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INVESTIGATION OF AIRCRAFT GAS TURBINE COMBUSTOR HAVING LOW MASS EMISSIONS

D. L. Troth, et al

General Motors Corporation

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By

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A. J. Verdouw

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April 1973

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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DETROIT DIESEL ALLISON
DIVISION OF GENERAL MOTORS CORPORATION
INDIANAPOLIS, INDIANA

U. S. ARMY MATERIEL COMMAND

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13. ABSTRACT

The objective of this one-year program was to develop and demonstrate emission abatement technology sufficient to obtain a 50% overall reduction in gas turbine engine mass emissions (CO, C_xH_y, NO_x and smoke) with no increase in any individual pollutant when tested over a typical Army light observation helicopter (LOH) duty cycle. The selected baseline was the Army T63-A-5A gas turbine engine combustor.

The program was conducted in three tasks:

- Task 1 - Problem Definition
- Task 2 - Concept Analysis and Selection
- Task 3 - Test

In Task 1, an LOH duty cycle was selected, the corresponding combustor operating conditions were defined, and an assessment was made of the emission problem for the selected LOH duty cycle. The selected duty cycle consisted of five operating points from idle (15% time) through maximum power (5% time). The results of Task 1 showed that the major pollutant from the T63-A-5A nonregenerative engine for the LOH duty cycle was carbon monoxide. It constituted 78% of the total pollution. For the regenerative T63 engine, both NO_x and CO were major pollutants, and their individual, respective contributions were 42% and 47%.

Task 2 was to analyze and select low-emission concepts. Three approaches used in this study task were emission reaction kinetic model predictions, empirical emission correlation prediction, and survey of previously published literature on experimental emissions performance of potential low-emission combustors.

In Task 3, combustor experiments were conducted in a combustor test rig which simulated the T63-A-5A engine combustor flow path. Six hundred seventy-three emission data points were obtained during the 246:40 hours of burning time. Task 3 was conducted in three phases: baseline combustor experiments, preliminary low-emission combustor experiments, and final low-emission combustor experiments.

The baseline combustor experiments were conducted with the conventional T63-A-5A combustor to establish the baseline emission index and to establish correlation between combustor rig and available engine emission data. Agreement between engine and rig total emission index was established within two percent.

Seventeen potential low-emission combustors, each incorporating one or more of the selected concepts, were tested to determine their emission performance. Experimental results indicated that several designs had the potential for meeting the program objectives.

Two combustors selected for final experimental evaluation were the "Prechamber" and "Modified Conventional." The low-emission feature in the "Prechamber" combustor was premix/prevaporization. The "Modified Conventional" combustor incorporated four low-emission features: airblast fuel atomization, delayed dilution, convection cooling, and variable geometry. Both of these combustors met the emission reduction objectives. Experimental results indicated that both of these liners can be developed to meet all other conventional T63 combustor requirements, i.e., light-off, temperature profile, durability, etc. The estimated development time for the "Prechamber" is longer than for the "Modified Conventional." However, the "Prechamber" combustor has better emission reduction potential when both combustors are designed as either fixed or variable geometry combustors.

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The research described herein was conducted by Detroit Diesel Allison under U. S. Army Contract DAAJ02-72-C-0005. The work was performed under the technical management of Mr. R. G. Dodd and Mr. L. E. Bell, Technology Applications Division, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory.

The objective of this contractual effort was to evaluate low-emission concepts theoretically and experimentally and to use the data generated in this effort to develop and demonstrate a combustor having 50% minimum reduction in total mass emissions. Two final combustors that meet the contract objectives were developed.

Appropriate technical personnel of this Directorate have reviewed this report and concur with the conclusions contained herein.

The findings and recommendations outlined herein will be considered in planning future small gas turbine engine and combustor component development programs.

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Contract DAAJ02-72-C-0005
USAAMRDL Technical Report 73-6
April 1973

INVESTIGATION OF AIRCRAFT GAS TURBINE COMBUSTOR HAVING LOW MASS EMISSIONS

Final Report

Detroit Diesel Allison Report EDR 7725

By

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F. J. Verkamp

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for

EUSTIS DIRECTORATE
U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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FOREWORD

The program reported herein was conducted for the U. S. Army Air Mobility Research and Development Laboratory, Eustis Directorate, under Contract DAAJ02-72-C-0005, DA Task 1G162207AA7102.

The authors are grateful for the significant contributions made to the program by other Detroit Diesel Allison (DDA) personnel. Mr. J. M. Vaught conducted the studies on the definition and selection of the LOH duty cycle. Dr. D. W. Clark provided the direction and personnel for the emission measurements. Mr. J. R. Williams directed the laboratory operations for acquiring and reducing the combustor performance data. Messrs. W. S. Sherman and W. H. Roberts were responsible for obtaining the combustor hardware at minimum cost, which made it possible to experimentally evaluate numerous low-emission combustors within the contract budget. Messrs. D. W. Austermiller, V. O. Hall, and E. Ward, Jr., installed and tested the combustors. Through their suggestions and efforts the installation and test time was reduced to the point that only one day was required for the installation and complete test of each combustor.

The authors are also grateful for the program guidance, suggestions, and LOH duty cycle data provided by Mr. Robert Dodd of the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, and Mr. Lawrence Bell of the U.S. Army Aviation Systems Command.

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LIST OF SYMBOLS

C	volumetric emissions concentration, ppm
CO	exhaust concentration of carbon monoxide, ppm
C_p	emission exhaust concentration, ppm
d_e	exhaust density, mg/standard cubic meter
d_s	true smoke density, mg/standard cubic meter
EI	emission index, lb emission/1000 lb fuel
F/A	fuel/air weight ratio
fr	volume fraction
K	curve fit coefficient
M	combustor overall airflow, lb/sec
M_e	exhaust molecular weight, lb/lb-mole
M_p	emission molecular weight, lb/lb-mole
NO_x	exhaust concentration of total oxides of nitrogen, ppm
P	combustor inlet pressure, psia
R_p	emission generation rate, lb emission/min
SN	smoke number (ARP 1179 Procedure)
T	combustor inlet temperature, °R
T_f	average flame temperature, °R
V	combustor predilution volume, in^3
W_a	combustor inlet airflow, lb/sec
W_e	exhaust mass flow, lb/min
W_f	fuel flow rate, lb fuel/min
η_b	combustion efficiency

INTRODUCTION

Measurements made on various gas turbine engines clearly show that the major air pollutants emitted from these engines are carbon monoxide (CO) and unburned hydrocarbons (C_xH_y) at low power settings and oxides of nitrogen (NO_x) and particulates at high power. The causes of these pollutants are known, being combustion inefficiency plus quenching effects in the case of CO and C_xH_y and high average and local flame temperatures in the case of NO_x. The cause of particulate (smoke) emission is fuel-rich, droplet combustion (carbon formation problem) and quenching of the carbon oxidation reactions prior to consumption (carbon consumption problem). It is therefore not difficult to conceive of alterations to the combustion, cooling, and dilution processes performed in the gas turbine combustor which will result in significantly reduced mass emissions.

Past emission abatement efforts in aircraft gas turbine engines have been directed primarily toward elimination of visible pollution - smoke. Future aircraft emission regulations will also require control of the nonvisible emissions - carbon monoxide, hydrocarbons, and nitrogen oxides over a specified aircraft duty cycle. Aircraft pollution regulations are contained in U.S. Public Law 91-604, "Clean Air Amendments of 1970," which was approved 31 December 1970. It requires the issuance of Federal regulations controlling exhaust emissions. These anticipated regulations will probably require reductions in all the mass emissions.

In addition to the ecological incentive for low-mass-emission combustors, there are many other potential benefits from low-emission combustion systems, such as:

- Noise reduction.
- Altitude ignition improvement.
- Specific fuel consumption reduction.
- Increased combustor life due to decreased liner temperature with reduced flame radiation.
- Longer turbine section life due to reduced erosion.

A one-year program plan was devised to provide emission abatement technology for aircraft gas turbine engine combustors. The selected baseline engine for the program was the Detroit Diesel Allison T63. There are two versions of this engine: nonregenerative and regenerative. Emission data was available for both versions. Some of the emission data is summarized in Table I.

TABLE I. TYPICAL T63 ENGINE EXHAUST EMISSIONS						
	T63 Nonregenerative			T63 Regenerative		
Power	CO	C_xH_y	NO_x	CO	C_xH_y	NO_x
(hp)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
50	950	88	11	250	45	32
200	290	11	40	91	9	68

The T63 operates with a more lean primary zone than most other conventional gas turbine engine combustors. Therefore, the T63 is relatively clean on NO_x emissions but dirty on CO and C_xH_y emissions. However, the emission trends are representative of the emission problems prevalent in all aircraft gas turbine engines.

The T63 is ideally suited for providing emission abatement technology at minimum cost because it is a can-type combustor, and a T63 combustor test rig was available for use in the program. The cost advantage of the can combustor was that the fabrication cost of the combustors incorporating low-emission concepts is considerably less than the fabrication cost of annular combustors employing the same concepts. Therefore, for the same program costs, many more emission reduction concepts could be experimentally investigated in can-type combustors than in annular combustors. The concepts which demonstrate emission reduction potential in the can combustors could be applied in future annular combustors.

Another advantageous feature of the T63 is the availability of both nonregenerative and regenerative versions of the engine. The nonregenerative version is representative of current helicopter gas turbine engines, and the combustor inlet temperature of the T63 regenerative engine is representative of future high-pressure-ratio helicopter gas turbine engines.

The objective of the program was to develop and demonstrate emission abatement technology sufficient to obtain a 50% reduction in total mass emissions (CO, C_xH_y, NO_x plus particulates) from the T63-A-5A nonregenerative engine when tested over a typical Army light observation helicopter (LOH) duty cycle. Constraints imposed in meeting the objective were

- No increase in individual pollutants.
- No significant NO_x increase at regenerative operating conditions.
- No degradation in baseline combustor durability and performance.

DISCUSSION

The program was separated into three tasks:

- Task 1 - Problem Definition
- Task 2 - Concept Analysis and Selection
- Task 3 - Test

Task 1 was to (1) select a representative LOH duty cycle, (2) define the corresponding combustor operating conditions, and (3) assess the emission problem for the selected LOH duty cycle.

Task 2 was to analyze and select low-emission, gas turbine engine combustor concepts. Three approaches to be used in this study task were (1) emission reaction kinetic model predictions, (2) empirical emission correlation predictions, and (3) survey of previously published literature on experimental emissions performance of potential low-emission combustors.

Task 3 was to obtain experimental emission and combustor performance data in a combustor test rig which simulated the T63-A-5A engine combustor flow path. Task 3 was to be conducted in four phases:

- Installation and check-out of T63-A-5A combustor test rig in the Detroit Diesel Allison Combustion Research Laboratory.
- Baseline T63 nonregenerative and regenerative combustor experiments to establish the baseline emission indices and to determine the correlation between combustor rig and available engine emission data.
- Experimental evaluation of preliminary, potential low-emission combustors, each incorporating one or more of the selected low-emission concepts.
- Experimental evaluation of final low-emission combustors.

The work conducted in each of the tasks is discussed in the following sections, and additional information on Task 3 is provided in Appendixes I through IV.

TASK 1 - PROBLEM DEFINITION

The purpose of the Task 1 activity was to establish, early in the program, those items necessary for the analysis and testing and also to compute and analyze the emissions from the baseline engine combustor. This phase of the program had three objectives:

1. Establish a computer model to calculate mass emissions (CO, C_xH_y, NO_x, and particulates) for a typical LOH duty cycle.

2. Calculate baseline, total mass emissions and specific mass emissions (CO, C_xH_y, NO_x, and particulates) for the LOH duty cycle using available DDA T63 emissions data.

3. Assess the relative importance of engine power settings and specific emissions on the total mass emissions for the LOH duty cycle.

To accomplish these objectives five subtasks were conducted in the order shown.

1. Define a typical LOH duty cycle.

2. Define the combustor operating conditions for each point in the LOH duty cycle.

3. Establish an emissions index computer program for the LOH duty cycle.

4. Calculate baseline engine emissions for both nonregenerative and regenerative operation.

5. Conduct the duty cycle assessment using the baseline engine emissions.

These subtasks will be discussed in the succeeding sections.

Define Army LOH Duty Cycle

The duty cycle typical of the U. S. Army's operation of a Light Observation Helicopter (LOH) was determined from the study of various duty cycles established for a variety of operational missions currently in use. The first of three duty cycles used was from a published report documenting OH-6A helicopters operating the armed combat scout missions flown by the 1st Cavalry Division in Vietnam[1]. The second duty cycle was based upon a typical commercial flight and was obtained from Detroit Diesel Allison Service Department studies of actual commercial operations.[2] The third duty cycle used was the duty cycle from the DDA 1000-Hour Simulated Flight Endurance (SFE)

Test Schedule,[3] which is comprised of 30 simulated operational missions. These mission profiles were obtained from the LOH Logistical Evaluation Tests made at Ft. Rucker, Alabama, and U. S. Army data on combat missions.

Each of these duty cycles differs in the length of flight and in the percentage of time in the cycle spent at idle and high power levels. Army flights such as scout, ferry, command control, and training missions are usually one or more hours long and contain considerable time at cruise power. Commercial flights are normally 10 to 20 minutes long and have a much higher proportion of idle, climb, and hover power levels required.

It was concluded that the probable use of the Army LOH aircraft in the United States would be a compromise between the military missions and flights having commercial characteristics. As a result of this conclusion, a combination duty cycle was evolved which was a mixture of military and commercial flight profiles. This preliminary duty cycle, shown in Table II, was further refined into the five-point composite duty cycle, used for this program, shown in Table III and Figure 1.

TABLE II. PRELIMINARY LOH DUTY CYCLE

Cycle Point	Mode	Power (%)	Weighting Factor
1	Flight Idle	0	.05
2	Ground Idle	10	.10
3	Takeoff	100	.05
4	Climb/Hover	75	.30
5	Cruise	55	.40
6	Descent	40	.10

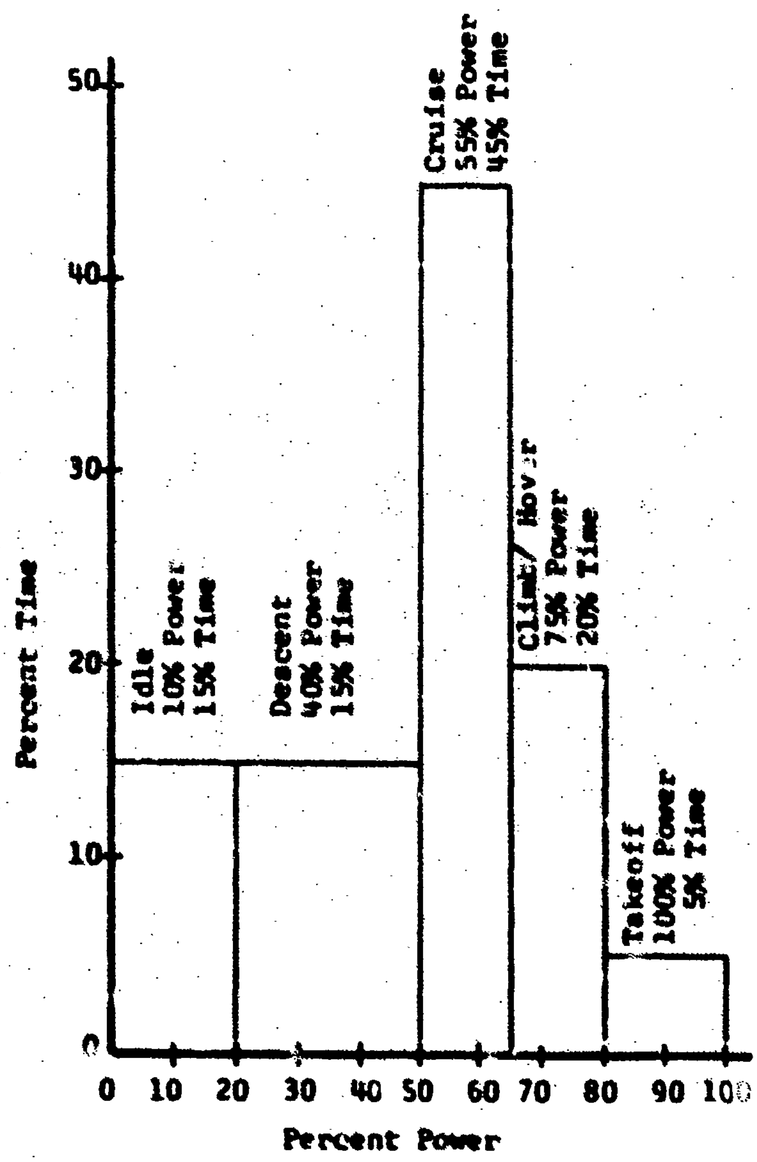


Figure 1. Composite T63-A-5A Army LOH Duty Cycle.

TABLE III. COMPOSITE LOH DUTY CYCLE			
Cycle Point	Mode	Power (%)	Weighting Factor
1	Ground Idle	10	.15
2	Takeoff	100	.05
3	Climb/Hover	75	.20
4	Cruise	55	.45
5	Descent	40	.15

The evaluation of total combustor emissions was based upon this duty cycle for all combustor liners tested under this contract. To fill the void between the 10% and 40% power points in the duty cycle, a sixth point at 25% power was retained for testing only. This 25% power point was not included in any numerical evaluations of combustor emissions.

Define Combustor Operating Conditions

The engine and combustion system operating conditions imposed by the LOH duty cycle were based upon actual engine test results.[4,5,6] Combustor operating conditions for the standard T63-A-5A nonregenerative engine were defined as well as combustor conditions for a T63 regenerative engine. These combustor conditions are presented in Tables IV and V for the nonregenerative T63-A-5A and for the regenerative T63 engines respectively.

All combustor testing performed in the evaluation of combustor liners was conducted at these six nonregenerative and six regenerative conditions. All combustor emission evaluations were performed using only five of the duty cycle combustor operating conditions. The 25% power emissions were not used in the calculation of total combustor liner emissions.

Emissions Index Computer Program

The evaluation of combustor liner emissions was based upon the calculation of an emission index (EI), which is defined as the mass of emissions (lb) per thousand mass units (1000 lb) of fuel over a defined duty cycle. For the investigation of low-emission combustors, the duty cycle used was the LOH duty cycle defined in Table III, and

TABLE IV. T63-A-5A COMBUSTION SYSTEM OPERATING CONDITIONS FOR NONREGENERATIVE ENGINE AT SELECTED LOW DUTY CYCLE CONDITIONS

CYCLE POINT	MODE	POWER (shp)	POWER (%)	R_c	GAS GEN (rpm)	$TOT_{T/C}$ (°R)	Wa (lb/sec)	W_f (lb/hr)	BIT (°R)	BIP (psia)	$TIT_{F/A}$ (°R)	F/A
1	Ground Idle	33.5	10	3.03	36,500	1273	1.87	73.7	760	44.5	1502	.0109
2	Takeoff	335.0	100	6.28	52,450	1840	3.22	229.5	984	92.3	2240	.0193
3	Climb/Hover	251.0	75	5.52	48,600	1653	2.98	178.5	932	81.0	2018	.0166
4	Cruise	184.0	55	4.87	45,700	1526	2.75	143.5	890	71.5	1850	.0145
5	Descent	134.0	40	4.34	43,350	1437	2.53	119.0	857	63.2	1749	.0131
		84.9	25	3.73	40,550	1360	2.20	96.0	813	54.8	1658	.0121

TABLE V. COMBUSTION SYSTEM OPERATING CONDITIONS FOR REGENERATIVE T63 ENGINE AT SELECTED LOW DUTY CYCLE CONDITIONS

CYCLE POINT	MODE	POWER (shp)	POWER (%)	R_c	GAS GEN (rpm)	TOT (°R)	W_a (lb/sec)	W_f (lb/hr)	BIT (°R)	BIP (psia)	$TIT_{F/A}$ (°R)	F/A
1	Ground Idle	28.0	10	2.93	36,000	1250	1.76	51	1137	43.0	[illegible]	.0080
2	Takeoff	280.0	100	5.8	50,000	1755	3.04	154	1450	85.0	2352	.0141
3	Climb/Hover	210.0	75	5.12	47,000	1608	2.61	122	1300	75.6	2090	.0131
4	Cruise	154.0	55	4.46	44,500	1490	2.42	101	1225	65.7	1900	.0107
5	Descent	112.0	40	4.1	42,400	1415	2.44	81	1175	60.2	1815	.0096
		70.0	25	3.5	39,400	1340	2.21	59	1161	51.5	1760	.0087

the combustor operating conditions corresponding to steady-state cycle points in this duty cycle were those defined in Tables IV and V for the nonregenerative and regenerative T63 engines.

A computer program[7] for the IBM 1130 computer was written which accepted the LOH duty cycle and the corresponding combustor operating conditions along with combustor emissions measured at those combustor conditions, and computed emission index values, emission rates, and the mass of emissions produced.

The computer sequence of calculations began by computing an emission rate for each pollutant type from the measured concentrations: ppm for CO, C_xH_y, NO, NO_2, and NO_x, and gm/min or smoke number (smoke index) for particulates. Once the emission rates were obtained in consistent units (lb/min), the weight of all emission constituents and the emission indices were computed for each duty cycle point. The constituent emission weights were summed over the duty cycle, providing the total emission mass produced, the average mass generation rate, and the average emission index for the constituent emissions separately and totally.

Because the emission concentrations were measured in different systems of units, three different equations were used to compute the rates of emission generation. For concentrations measured in parts per million (ppm), the following equation was used to compute the generation rate:

$$R_p = C_p W_e \left(\frac{M_p}{M_e} \right) 10^{-6} \tag{1}$$

where R_p = emission generation rate, lb/min

C_p = emission exhaust concentration, ppm

W_e = exhaust mass flow, lb/min

M_p = emission molecular weight, lb/lb-mole

M_e = exhaust molecular weight, lb/lb-mole

Emission concentrations for carbon monoxide (CO), hydrocarbons (C_xH_y), and nitrogen oxides (NO, NO_2, and NO_x) were all measured in ppm.

Mass particulate concentrations in the exhaust were reported as smoke number and were determined using the Aerospace Recommended Practice (ARP) 1179 as determined by the SAE in 1970. The numerical conversion from smoke number to true smoke density was accomplished by utilizing a correlation developed by Stanforth and reported by Champagne.[8] The semilogarithmic curve reported by Champagne was

fitted with the following numerical relationship:

$$d_s = K_{1a} \exp(K_{1b} SN) [1 - \exp(-K_2 SN)] + K_{3a} \exp[- K_{3b} (SN - K_{3c})^2] \quad (2)$$

where d_s = true smoke density, mg/standard cubic meter

SN = smoke number (ARP 1179 Procedure)

K_{1a} = 0.8

K_{1b} = 0.057565

K_2 = 0.1335

K_{3a} = 0.0942

K_{3b} = 0.005

K_{3c} = 27.5

Stanforth concluded that because the filtration type smoke measuring system was insensitive to large particle sizes (above 1-micron), which may comprise as much as 50% of the total carbon by weight, the true smoke density may be anywhere from the value computed in Equation (2) to 100 percent greater for a given value of smoke number. Therefore, for this contract the generation rate for particulates was based on a true smoke density twice the value computed in Equation (2). The generation rate equation used was then

$$R_p = 2 W_e \left(\frac{d_s}{d_e} \right) \quad (3)$$

where R_p = emission generation rate, lb/min

W_e = exhaust mass flow, lb/min

d_s = smoke density, mg/standard cubic meter

d_e = exhaust density, mg/standard cubic meter

Mass particulate concentrations from baseline nonregenerative and regenerative T63 engines were expressed as generation rates in grams/minute. This system required only a simple change in units from grams

to pounds, and the required units were obtained for the emission generation rate.

In all emission calculations based on the approved LOH duty cycle, the exhaust mass flow was assumed to be equal to the combustor inlet mass flow of compressor discharge air. The mass of fuel was not included in the exhaust mass flow. Since the fuel flow was only 1% - 2% of the inlet airflow, emission comparisons were practically unaffected even though the absolute magnitudes used in the comparisons were slightly low.

Once the emission generation rates were computed for each emission constituent at each duty cycle point, the mass of each constituent at each cycle point was easily computed (the rate times the time), and the emissions indices were computed. The emission index (EI) equation used was:

$$EI = \frac{1000\ R_p}{W_f} \tag{4}$$

where EI = emission index, lb pollutant/1000 lb fuel

R_p = emission generation rate, lb pollutant/min

W_f = fuel flow rate, lb fuel/min

The average duty cycle emission index for each pollutant was computed based on the total mass of that pollutant generated over the duty cycle and the total mass of fuel used. The total emission index was then the sum of the constituent emission indices.

Calculate Baseline Emissions

The baseline T63 nonregenerative and regenerative engine emissions were available from test data previously measured on these engines and documented in a DDA internal report. From curves of emissions as a function of shaft horsepower, the baseline emissions were obtained for each of the power levels defined by the LOH duty cycle. The engine emissions for the nonregenerative T63-A-5A engine and for the regenerative T63 engine are shown in Table VI and Table VII. Hydrocarbon concentrations are given in parts/million of propane (C_3H_8, molecular weight 44), and total nitrogen oxides (NO_x) are given in parts/million of nitrogen dioxide (NO_2, molecular weight 46).

Applying the baseline engine emissions to the emission index computer calculation for the LOH duty cycle, the baseline engine emission index values were computed for both the nonregenerative and regenerative T63 engines. The computer results of these calculations are presented in Table VIII and Table IX. From the baseline engine

TABLE VI. BASELINE NONREGENERATIVE T63-A-5A ENGINE EMISSIONS

Cycle Point	Mode	Engine Power Level (hp)	Engine Power Level (%)	Engine Exhaust Emissions: CO (ppm)	C_3H_8 (ppm)	NO_x (ppm)	Particulates (gm/min)
1	Ground Idle	33.5	10	1100	133	10	.300
2	Takeoff	335.0	100	160	3	82	1.196
3	Climb/Hover	251.0	75	220	6	54	.804
4	Cruise	184.0	55	320	11	36	.588
5	Descent	134.0	40	470	22	22	.471

TABLE VII. BASELINE REGENERATIVE T63 ENGINE EMISSIONS

Cycle Point	Mode	Engine Power Level (hp)	Engine Power Level (%)	Engine Exhaust Emissions: CO (ppm)	C_3H_8 (ppm)	NO_x (ppm)	Particulates (gm/min)
1	Ground Idle	28.0	10	330	60	28	.125
2	Takeoff	280.0	100	50	3	98	.309
3	Climb/Hover	210.0	75	75	6	79	.272
4	Cruise	154.0	55	100	10	64	.240
5	Descent	112.0	40	120	15	52	.200

TABLE VIII. BASELINE T63 NONREGENERATIVE ENGINE EMISSIONS INDEX VALUES

GAS TURBINE ENGINE - DUTY CYCLE EMISSIONS

BASELINE NON-REGENERATIVE T63-A-5A ENGINE EMISSIONS - LOH MISSION 30 SEPT 1971

**** INPUT DATA *****

CYCLE POINT	ENGINE POWER LEVEL HP	ENGINE POWER LEVEL PERCENT	CYCLE POINT TIME MIN	CYCLE POINT TIME PERCENT	AIR FLOW LB/SEC	FUEL FLOW LB/HR	FUEL/AIR RATIO
1	33.50	10.00	9.00	15.00	1.87	73.70	0.01094
2	335.00	100.00	3.00	5.00	3.22	229.50	0.01979
3	251.00	75.00	12.00	20.00	2.98	178.50	0.01663
4	184.00	55.00	27.00	45.00	2.75	143.50	0.01449
5	134.00	40.00	9.00	15.00	2.53	119.00	0.01306
			60.00	100.00		140.65 LB	

CYCLE POINT	C3H8-PPM	CO-PPM	NO-PPM	NO2-PPM	NOX-PPM	PAR1-G/M	PAR2- SN
	* * * EMISSION CONCENTRATIONS BY TYPE * * *						
1	133.00	1100.00	0.00	0.00	10.00	0.300000	0.00
2	3.00	160.00	0.00	0.00	82.00	1.196000	0.00
3	6.00	220.00	0.00	0.00	54.00	0.804000	0.00
4	11.00	320.00	0.00	0.00	36.00	0.588000	0.00
5	22.00	470.00	0.00	0.00	22.00	0.471000	0.00
MOL WT =	44.00	28.00	46.00	46.00	46.00		

**** OUTPUT DATA *****

CYCLE POINT	C3H8	CO	NO	NO2	NOX	PAR1	PAR2
	* * * EMISSIONS INDEX BY TYPE - LB/1000 LB FUEL * * *						
1	18.496	97.348	0.000	0.000	1.453	0.537	0.000
2	0.230	7.829	0.000	0.000	6.592	0.688	0.000
3	0.549	12.810	0.000	0.000	5.165	0.595	0.000
4	1.155	21.389	0.000	0.000	3.953	0.541	0.000
5	2.563	34.852	0.000	0.000	2.680	0.523	0.000
CYCLE =	2.467	25.784	0.000	0.000	4.118	0.564	0.000
	TOTAL OF ALL EMISSION TYPES FOR ALL CYCLE POINTS =						32.934

CYCLE POINT	C3H8	CO	NO	NO2	NOX	PAR1	PAR2
	* * * EMISSION WEIGHTS BY TYPE - LB * * *						
1	0.20447	1.07618	0.00000	0.00000	0.01607	0.00594	0.00000
2	0.00264	0.08984	0.00000	0.00000	0.07564	0.00790	0.00000
3	0.01959	0.45733	0.00000	0.00000	0.18441	0.02125	0.00000
4	0.07460	1.38120	0.00000	0.00000	0.25527	0.03496	0.00001
5	0.04576	0.62211	0.00000	0.00000	0.04784	0.00933	0.00000
TOTAL =	0.34709	3.62668	0.00000	0.00000	0.57925	0.07940	0.00003
	TOTAL OF ALL EMISSION TYPES FOR ALL CYCLE POINTS =						4.63244

CYCLE POINT	C3H8	CO	NO	NO2	NOX	PAR1	PAR2
	* * * EMISSION RATES BY TYPE - - LB/MIN * * *						
1	0.02271	0.11957	0.00000	0.00000	0.00178	0.00066	0.00000
2	0.00088	0.02994	0.00000	0.00000	0.02521	0.00263	0.00000
3	0.00163	0.03811	0.00000	0.00000	0.01536	0.00177	0.00000
4	0.00276	0.05115	0.00000	0.00000	0.00945	0.00129	0.00000
5	0.00508	0.06912	0.00000	0.00000	0.00531	0.00103	0.00000
CYCLE =	0.00578	0.06044	0.00000	0.00000	0.00965	0.00132	0.00000
	TOTAL OF ALL EMISSION TYPES FOR ALL CYCLE POINTS =						0.07720

TABLE IX. BASELINE T63 REGENERATIVE ENGINE EMISSIONS INDEX VALUES

GAS TURBINE ENGINE - DUTY CYCLE EMISSIONS

BASELINE REGENERATIVE T63-A-5A ENGINE EMISSIONS - LOH MISSION 30 SEPT 1971

**** INPUT DATA *****

CYCLE POINT	ENGINE POWER LEVEL HP	ENGINE POWER LEVEL PERCENT	CYCLE POINT TIME MIN	CYCLE POINT TIME PERCENT	AIR FLOW LB/SEC	FUEL FLOW LB/HR	FUEL/AIR RATIO
1	28.00	10.00	9.00	15.00	1.76	51.00	0.00804
2	280.00	100.00	3.00	5.00	3.04	154.00	0.01407
3	210.00	75.00	12.00	20.00	2.81	122.00	0.01206
4	154.00	55.00	27.00	45.00	2.62	101.00	0.01070
5	112.00	40.00	9.00	15.00	2.46	83.00	0.00937
			60.00	100.00		97.64 LB	

CYCLE POINT	* * * EMISSION CONCENTRATIONS BY TYPE * * * C3H8-PPM	CO-PPM	NO-PPM	NO2-PPM	NOX-PPM	PAR1-G/M	PAR2- SN
1	60.00	330.00	0.00	0.00	28.00	0.125000	0.00
2	3.00	50.00	0.00	0.00	98.00	0.309000	0.00
3	6.00	75.00	0.00	0.00	79.00	0.272000	0.00
4	10.00	100.00	0.00	0.00	64.00	0.240000	0.00
5	15.00	120.00	0.00	0.00	52.00	0.200000	0.00
MOL WT =	44.00	28.00	46.00	46.00	46.00		

**** OUTPUT DATA *****

CYCLE POINT	* * * EMISSIONS INDEX BY TYPE - LB/1000 LB FUEL * * * C3H8	CO	NO	NO2	NOX	PAR1	PAR2
1	11.348	39.720	0.000	0.000	5.536	0.323	0.000
2	0.324	3.442	0.000	0.000	11.065	0.265	0.000
3	0.757	6.025	0.000	0.000	10.426	0.294	0.000
4	1.421	9.047	0.000	0.000	9.513	0.314	0.000
5	2.436	12.405	0.000	0.000	8.831	0.318	0.000
CYCLE =	2.076	10.681	0.000	0.000	9.466	0.306	0.000
	TOTAL OF ALL EMISSION TYPES FOR ALL CYCLE POINTS =						22.531

CYCLE POINT	* * * EMISSION WEIGHTS BY TYPE - LB * * * C3H8	CO	NO	NO2	NOX	PAR1	PAR2
1	0.08681	0.30386	0.00000	0.00000	0.04235	0.00247	0.00000
2	0.00249	0.02650	0.00000	0.00000	0.08535	0.00204	0.00000
3	0.01848	0.14701	0.00000	0.00000	0.25440	0.00718	0.00000
4	0.06462	0.41122	0.00000	0.00000	0.43237	0.01427	0.00000
5	0.03033	0.15444	0.00000	0.00000	0.10994	0.00396	0.00000
TOTAL =	0.20275	1.04305	0.00000	0.00000	0.92443	0.02994	0.00000
	TOTAL OF ALL EMISSION TYPES FOR ALL CYCLE POINTS =						2.20019

CYCLE POINT	* * * EMISSION RATES BY TYPE - - LB/MIN * * * C3H8	CO	NO	NO2	NOX	PAR1	PAR2
1	0.00964	0.03376	0.00000	0.00000	0.00470	0.00027	0.00000
2	0.00083	0.00883	0.00000	0.00000	0.02845	0.00068	0.00000
3	0.00154	0.01225	0.00000	0.00000	0.02120	0.00059	0.00000
4	0.00239	0.01523	0.00000	0.00000	0.01601	0.00052	0.00000
5	0.00337	0.01716	0.00000	0.00000	0.01221	0.00044	0.00000
CYCLE =	0.00337	0.01738	0.00000	0.00000	0.01540	0.00049	0.00000
	TOTAL OF ALL EMISSION TYPES FOR ALL CYCLE POINTS =						0.03665

emissions, the total emission index for the nonregenerative T63-A-5A engine was 32.934 lb emission /1000 lb fuel over the LOH duty cycle. For the regenerative T63 engine the total emission index was 22.531 lb emission /1000 lb fuel.

The contract objective of a 50% minimum reduction in total emissions required the final combustor(s) to produce no more than 16.5 lb emission /1000 lb fuel when tested at the nonregenerative combustor conditions of the LOH duty cycle.

Duty Cycle Assessments

An assessment was made of the baseline T63 emission data for the approved LOH mission duty cycle. These baseline data are presented in Tables VI and VII for the nonregenerative and the regenerative T63 engines respectively. The approach used was to quantify the percentage contribution to total emissions from each emission type at each cycle point. Conclusions could then be drawn toward identifying the most promising areas for concentration of effort to reduce the total emission level.

The evaluation to identify the major contributors to the total emissions was dependent on the chosen duty cycle, the pollutant concentrations, and the airflow. The baseline T63 engine emission data over the approved LOH duty cycle, were analyzed by determining the mass of emission produced by each pollution constituent for each portion of the duty cycle. These individual values were then summed three ways: by constituent for the entire cycle, by duty cycle point for all constituents, and by all constituents for the entire duty cycle. These results for the nonregenerative and the regenerative T63 baseline engines are shown in Tables X and XI. For each pollutant at each LOH duty cycle point, the exhaust concentration and the percentage contribution to the total duty cycle mass emission are given. The "cycle point total" column shows the contribution in percent to total emission supplied at each duty cycle point. The "cycle total" row at the bottom of the table shows the total duty cycle contribution of each constituent to the emission total.

Analysis of the data presented in Tables X and XI shows the critical areas where effort must be concentrated to reduce the level of total emissions. The following are the important conclusions drawn from the data in Table X concerning the nonregenerative engine emissions.

1. Because of its high concentrations, carbon monoxide is the largest constituent contributor of mass emissions, producing 78.3% of the total. To obtain the 50% minimum reduction in total emissions, carbon monoxide must be significantly reduced.

TABLE X. NONREGENERATIVE T63-A-5A ENGINE BASELINE EMISSIONS PERCENT CONTRIBUTION TO EMISSION TOTAL

CYCLE POINT	WEIGHTING FACTOR	C_3H_8 (ppm)	C_3H_8 (%)	CO (ppm)	CO (%)	NO_x (ppm)	NO_x (%)	PARTICULATES (gm/min)	PARTICULATES (%)	CYCLE POINT TOTAL (%)
1	.15	133.	4.4	1100.	23.2	10.	.3	.300	.1	28.1
2	.05	3.	.1	160.	1.9	82.	1.6	1.196	.2	3.8
3	.20	6.	.4	220.	9.9	54.	4.0	.804	.5	14.7
4	.45	11.	1.6	320.	29.8	36.	5.5	.588	.8	37.7
5	.15	22.	1.0	470.	13.4	22.	1.0	.471	.2	15.7
CYCLE TOTAL	1.00	23.85	7.5	391.70	78.3	38.08	12.5	.600	1.7	100.0

TABLE XI. REGENERATIVE T63-A-5A ENGINE BASELINE EMISSIONS PERCENT CONTRIBUTION TO EMISSION TOTAL

CYCLE POINT	WEIGHTING FACTOR	C_3H_8 (ppm)	C_3H_8 (%)	CO (ppm)	CO (%)	NO_x (ppm)	NO_x (%)	PARTICULATES (gm/min)	PARTICULATES (%)	CYCLE POINT TOTAL (%)
1	.15	60.	3.9	330.	13.9	28.	1.9	.125	.1	19.8
2	.5	3.	.1	50.	1.2	98.	3.9	.309	.1	5.3
3	.20	6.	.8	75.	6.7	79.	11.6	.272	.3	19.4
4	.45	10.	2.9	100.	18.7	64.	19.7	.240	.6	41.9
5	.15	15.	1.4	120.	7.0	52.	5.0	.200	.2	13.6
CYCLE TOTAL	1.00	14.64	9.2	118.37	47.4	63.86	42.0	.226	1.4	100.0

2. Because of their relatively small contribution to the total emissions, care must be taken to insure that the remaining constituents do not increase above baseline levels.

3. Cycle point 4 (55% power) is the major emission contributor, due mainly to its high weighting factor of 0.45.

4. Since carbon monoxide and hydrocarbons have such high concentrations at cycle point 1 (10% power), this cycle point ranks a close second in the magnitude of emissions produced, with 28.1% of the total. The overriding influence of carbon monoxide is clearly seen here.

It therefore appears that the greatest reduction in total emissions could be made by concentrating on carbon monoxide. Decreasing the concentrations of hydrocarbons, oxides of nitrogen, and particulates is important, but it would have only secondary effects on the total emission index.

The important conclusions drawn from the figures in Table XI concerning the regenerative engine emissions are as follows:

1. For the regenerative engine, the major constituent contributors are carbon monoxide, 47.4%, and nitrogen oxides, 42.0%. To significantly reduce the total emissions in the regenerative engine, a definite advancement in technology is required to lower the production of CO and NO_x simultaneously.

2. Because of its 0.45 weighting factor, cycle point 4 (55% power), is the major cycle point contributor of emissions. Cycle point 1 (10% power), and cycle point 3 (75% power), contribute nearly identical amounts of emissions, and together they produce nearly as much as cycle point 4.

It is apparent that reductions in emissions in this regenerative engine can be realized only if all constituent emissions are lowered at all operating conditions.

Calculations were made to assess the effect of variable combustor geometry for reducing the EI using T63 baseline emissions data. The approach taken was to assume that variable geometry could maintain any cycle point emission concentration constant at all combustor operating conditions. Using this approach and the baseline emission concentrations, each cycle point concentration was held constant over the entire duty cycle. The resulting EI values for both nonregenerative and regenerative emission baselines are given in Tables XII and XIII. Summing the EI's of the four emission constituents produced the total pollutant EI levels shown in the right-hand column. These would be the EI levels if the combustor operated over the entire

TABLE XII. EFFECT OF CONSTANT EMISSION CONCENTRATION AT CYCLE POINTS OVER TOTAL CYCLE FOR NONREGENERATIVE T63-A-5A BASELINE ENGINE EMISSIONS

CYCLE POINT	HP (%)	C_3H_8 (ppm)	C_3H_8 EI	CO (ppm)	CO EI	NO_x (ppm)	NO_x EI	PARTICULATES (gm/min)	PARTICULATES EI	TOTAL POLLUTANT EI
1	10	133.	13.76	1100.	72.41	10.	1.08	.300	.28	87.53
2	100	3.	.31	160.	10.53	82.	8.87	1.196	1.12	20.83
3	75	6.	.62	220.	14.48	54.	5.84	.804	.76	21.70
4	55	11.	1.41	320.	21.06	36.	3.89	.588	.55	26.64
5	40	22.	2.28	470.	30.94	22.	2.38	.471	.44	36.04
TOTAL CYCLE	52	23.8	2.47	391.7	25.78	38.1	4.12	.600	.56	32.93

TABLE XIII. EFFECT OF CONSTANT EMISSION CONCENTRATION AT CYCLE POINTS OVER TOTAL CYCLE FOR REGENERATIVE T63-A-5A BASELINE ENGINE EMISSIONS

CYCLE POINT	HP (%)	C_3H_8 (ppm)	C_3H_8 EI	CO (ppm)	CO EI	NO_x (ppm)	NO_x EI	PARTICULATES (gm/min)	PARTICULATES EI	TOTAL POLLUTANT EI
1	10	60.	8.51	330.	29.78	28.	4.15	.125	.17	42.61
2	100	3.	.43	50.	4.51	98.	14.53	.309	.42	19.89
3	75	6.	.85	75.	6.77	79.	11.71	.272	.37	19.70
4	55	10.	1.42	100.	9.02	64.	9.49	.240	.32	20.25
5	40	15.	2.13	120.	10.83	52.	7.71	.200	.27	20.94
TOTAL CYCLE	52	14.6	2.08	118.4	10.68	63.9	9.47	.226	.31	22.53

cycle at the pollution concentrations of the given cycle points. The baseline EI totals are 32.93 for the nonregenerative engine. and 22.53 for the regenerative engine. These results are shown graphically in Figure 2.

The last line on Tables XII and XIII gives the baseline EI for each emission type. The concentration given is the average concentration which, if held constant over the LOH cycle profile, would result in the baseline EI for that emission type.

It is apparent that variable geometry would help reduce emissions, especially for the nonregenerative combustor, but for no cycle point condition would the 50% reduction goal be achieved.

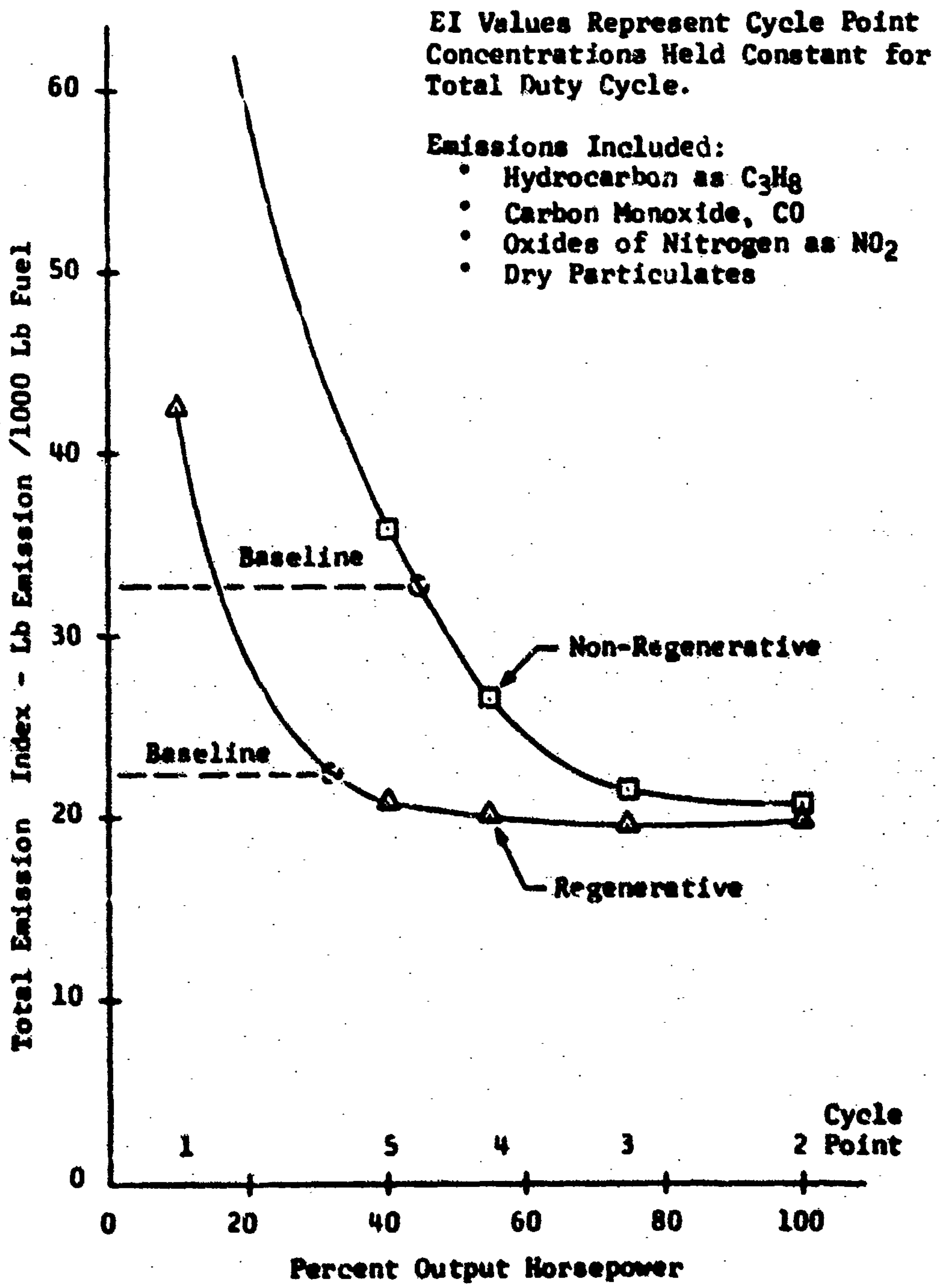


Figure 2. T63-A-5A Engine Emissions Index Variable-Geometry Combustor Assessment.

TASK 2 - CONCEPT ANALYSIS AND SELECTION

The purpose of this contract was to apply concepts, previously shown to be basically feasible, to an aircraft gas turbine combustor and to evaluate these concepts by tests which culminate in demonstration of a combustor having significantly reduced emissions of CO, C_xH_y, NO_x, and particulates. Specifically, emission abatement techniques were to be incorporated into a Detroit Diesel Allison T63-A-5A combustor which, when evaluated over an approved Light Observation Helicopter (LOH) duty cycle, would demonstrate a minimum total mass emission reduction of 50%, with no increase in constituent emissions.

To provide directions for achieving the contract goal of emission abatement, Task 2, Concept Analysis and Selection, was devised for the purpose of analyzing potential emission reduction concepts and[9] selecting the most promising for fabrication and experimental test. The approaches used in analysis of emission abatement concepts were threefold in nature:

- Reaction Kinetics Predictions.
- Empirical Correlation Predictions.
- Combustor Emission Test Data.

These approaches were applied where possible toward evaluating a variety of potential emission abatement concepts which have demonstrated reductions in gas turbine engines. A general listing of these potential concepts is as follows:

- Lean primary zone.
- Rich primary zone.
- Early quench.
- Water injection.
- Cold primary zone air injection.
- Staged fuel injection.
- Variable geometry.
- Heat rejection from primary zone.
- Swirl primary zone.
- Premix and vaporizer fuel injectors.

- Massive primary zone recirculation.
- Reverse flow primary zone.
- Different combustor volume.
- Plug flow.

The purpose of this section is to state the conclusions reached as a result of the Task 2 studies along with the combustor concepts recommended for fabrication and experimental testing in Task 3 of this contract. Reported first are the detailed results of the approaches used in the evaluation of the potential concepts along with the compilation of these results and the ensuing decisions culminating in selection of the preliminary combustor concepts.

The emission abatement concepts investigated can be grouped into three areas, depending upon the portion of the combustor that is modified by the concept. These areas are the fuel injector, the primary zone, and the primary-dilution zone. The potential combustor concepts investigated in Task 2 were the following:

- Fuel Injector

  Air Blast/Air Assist

  Premix and Vaporizer

  Staged

- Primary Zone

  Lean

  Rich

  Variable Geometry

  Early Quench

  Reverse Flow

  Massive Recirculation

  Swirl

  Heat Rejection

  Water Injection

  Cold Air Injection

- Primary Dilution Zone

  Increased Length

  Double Combustor Volumes

  Rapid Plug Flow

The approaches used in the analysis and selection of the concepts in Task 2 were threefold: reaction kinetics predictions, empirical correlation predictions, and the published results of experimental tests. The analyses and results from these approaches will be presented along with a summary which will enumerate the decisions made concerning each combustor considered.

Reaction Kinetics Analyses

An analytical computer program[10] to predict carbon monoxide, unburned hydrocarbon, nitric oxide, and nitrogen dioxide emissions in a gas turbine combustor is being developed in the Combustion Research Section at DDA. The accomplishments to date have resulted in a finite-rate hydrocarbon combustion reaction mechanism model.[11, 12] This part of the computer program is operational and can be used to predict emission trends as a function of fuel-air ratio, inlet temperature, pressure, and volume (residence time).

The reaction mechanism combines a global rate equation for the breakdown of hydrocarbons to carbon monoxide and hydrogen with finite-rate equations for the combustion of carbon monoxide and hydrogen and the formation of nitrogen oxides. Fifteen species are included: C_xH_y (hydrocarbon fuel), Ar, CO, CO_2, H, H_2, H_2O, N, N_2, NO, NO_2, N_2O, O, O_2, and OH.

A flow model for the macroscopic combustion process, the perfectly stirred reactor model, was developed which applied the chemical reaction mechanism model to an ideal mathematical combustion system. For the Task 2 reaction kinetics analyses, an approximate plug flow model was compiled which divided each combustion volume into a finite number of perfectly stirred reactors in series. Studies using this approximate model revealed a critical sensitivity of the carbon monoxide exhaust concentrations to the subvolume size or number of subvolume steps within each zone. For use in this model the T63 combustor was divided into four zones, as indicated in the sketch in Figure 3. The last three zones are the plug flow zones and are divided in subvolumes. As is evident from the plot in Figure 3, the CO concentration is very sensitive to the number of subvolumes in Zone II. In this figure, two different techniques of zone subdividing were investigated. In the first method an equal number of volumes in each zone was defined; for the three plug flow sections, this required many total subvolumes and long computer running times for the calculation. The second technique

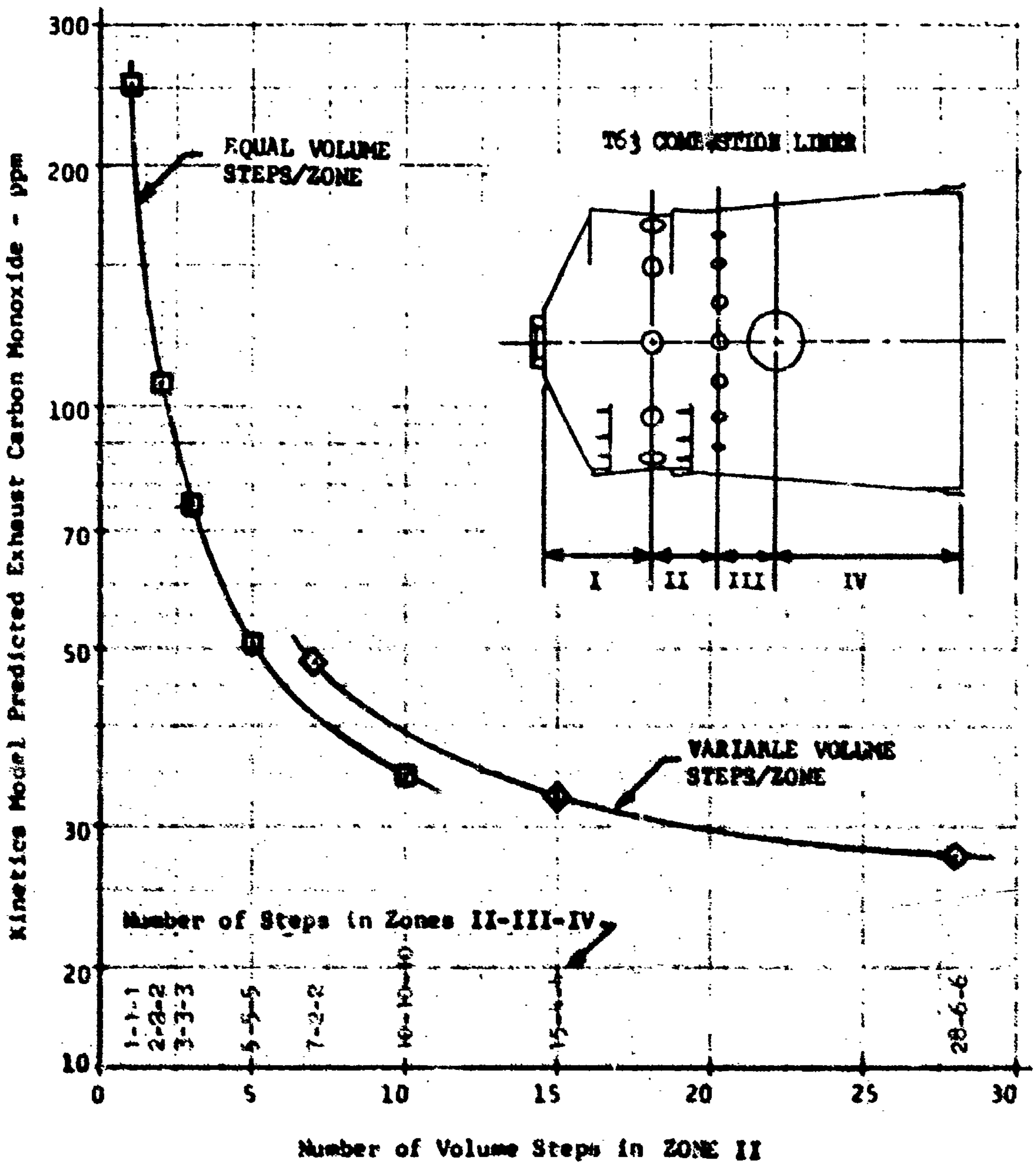


Figure 3. Carbon Monoxide Sensitivity to Volume Step Size in Combustion Kinetics Model.

selected subvolume sizes which allowed the constituent concentration to change by a specified percentage. Thus each zone could have a different number of subvolumes. It was found that Zone II was the most critical zone and required the largest number of subvolumes. As is indicated, to most accurately predict exhaust carbon monoxide concentrations, the approximate model must approach a precise model, i.e., an infinite number of subvolumes per zone. The selection of the number of subvolumes per zone was a compromise between computer running time and consistent results.

Even though the CO exhibited a marked sensitivity to the number of steps per zone, the oxides of nitrogen concentrations showed almost no variation for those combinations defined in Figure 3. The important result of this sensitivity study was the indication that for reduction in carbon monoxide the combustor must convert to plug flow as quickly as possible.

Of the eighteen concepts investigated in the Task 2 studies, only eleven could be analyzed with the reaction kinetics model. Those combustors investigated with the reaction kinetics model are listed in Table XIV. The procedure in the kinetics analysis was to schematically define each combustor concept, including the baseline combustor (standard T63-A-5A). Carbon monoxide and total oxides of nitrogen concentration predictions were computed for each design at each duty cycle operating point. The concentrations were then used as input to the duty cycle emission index calculations. The resulting emission index (EI) for CO and NO_x is listed in Table XIV.

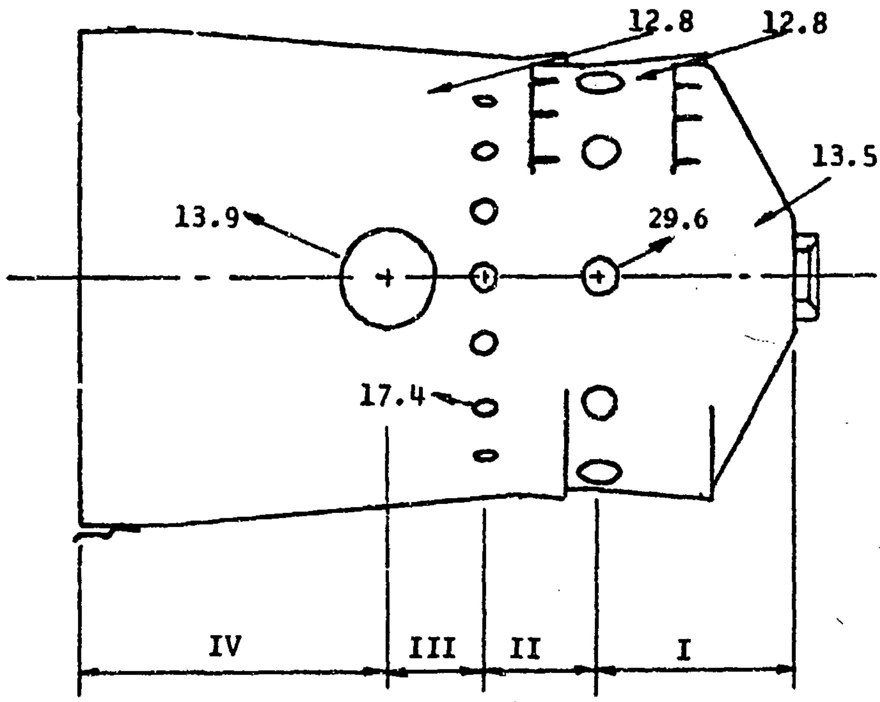
The reaction kinetics standard T63-A-5A combustor model is given in Figure 4. The predicted CO and NO_x emissions are compared with the emissions measured on the test rig in Figure 5. From this figure, it is apparent that neither CO nor NO_x reductions are limited from a kinetics standpoint. The following sections will discuss the results of the kinetics investigations of the concepts listed in Table XIV.

Lean Primary Zone

In this design the hole sizes were changed to produce a lean primary zone having an equivalence ratio of 0.50. The predicted emissions showed a significant increase in CO with a similar decrease in NO_x. These differences are quantified in the EI values in Table XIV. Leaning the primary zone simply trades a decrease in NO_x for an increased CO concentration, which is not acceptable. Were there a design which would allow this type of constituent tradeoff, leaning the primary zone would be helpful.

TABLE XIV. EMISSION ABATEMENT COMBUSTOR CONCEPT COMPARISON FOR REACTION KINETICS ANALYSIS

COMBUSTOR CONCEPT NO.	DESCRIPTION	EMISSION INDEX LB EMISSIONS/1000LB FUEL CO	NO_x	$CO + NO_x$
00	Baseline T63 (Rig Test)	26.094	4.648	30.742
0	(Prediction)	.939	.617	1.556
	PRIMARY ZONE			
4a	Lean (ϕ = .35)	-	-	-
4b	(ϕ = .50)	3.864	.102	3.966
5a	Rich (ϕ = 1.0)	.456	6.161	6.617
6	Variable Geometry	.480	.405	.885
7a	Early Quench	.612	.404	1.016
11	Heat Rejection	8.567	.040	8.607
12	Water Injection	.897	.200	1.097
	PRIMARY-DILUTION ZONE			
14a	Increased Length (+100%)	-	-	-
14b	(+200%)	.210	.676	.886
15	Double Combustor Volumes	.202	.996	1.198
16a	Double Length (ϕ = .68)	.486	.643	1.129
16b	(ϕ = .5)	2.370	.107	2.477
17	Rapid Plugged Flow	.545	.617	1.162



Section	Volume (in.^{3})	% Flow
I	43.3	43.1
II	30.9	12.8
III	32.5	17.4
IV	113.0	26.7

Figure 4. Reaction Kinetics Combustor Model for Conventional T63-A-5A Combustor Liner.

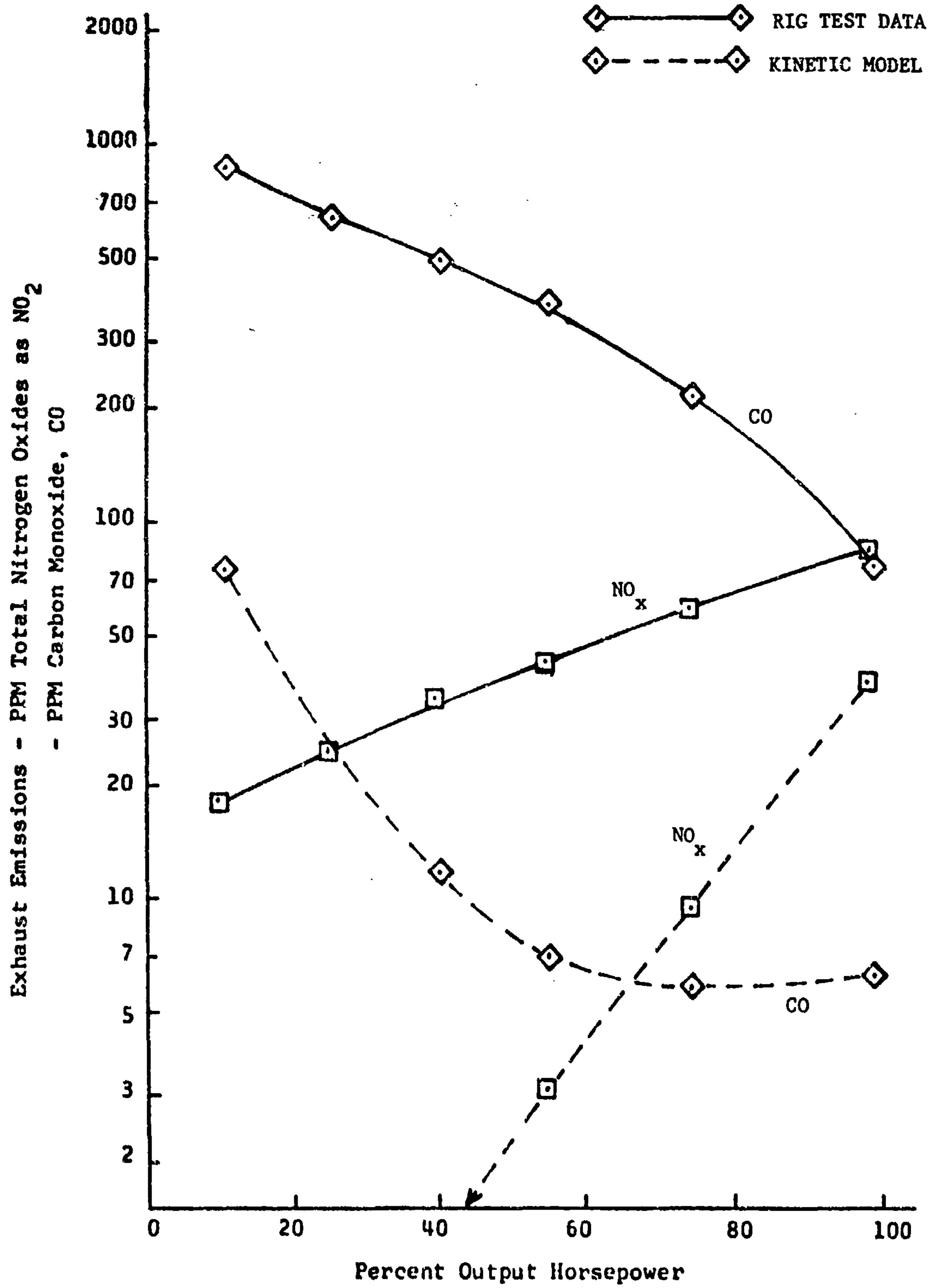


Figure 5. Reaction Kinetics Predicted Emission Comparison With Rig Test Data for T63 Baseline Liner.

Rich Primary Zone

The rich primary zone combustor incorporated a 1.0 equivalence ratio primary zone. This design showed the reverse trend of the lean primary zone combustor. The CO was reduced but at the expense of a greatly increased NO_x concentration.

Variable Geometry

The variable-geometry primary zone equivalence ratios for each LOH duty cycle point were optimized for minimum total cycle EI with no constituent increase using the empirical correlation equations to be discussed in subsequent sections. These geometries, itemized in Table XV, were analyzed with the kinetics model. As can be seen from Table XIV, both the CO and the NO_x total mass emissions were reduced. Therefore, variable geometry could probably be used to reduce the total emissions of any fixed-geometry combustor.

Early Quench

In this design, the first row of holes was moved upstream to a point where the primary zone volume was reduced to half its standard value. The reaction kinetics model predicted a 35% reduction in both CO and NO_x total emissions. Therefore, this concept should be further investigated in the Task 3 testing.

Heat Rejection

It was assumed in this configuration that a standard combustor experienced sufficient primary zone heat transfer to reduce the primary zone average temperature by 600°F. The predicted emissions showed a great increase in CO and a similarly great reduction in NO_x concentrations. Again, if tradeoffs among constituent emissions were possible, this technique might be beneficial.

Water Injection

This concept was a standard combustor with 1.5 pounds of water per pound of fuel introduced into the primary zone at the 75% and 100% power operating conditions. The kinetics model showed a significant reduction in NO_x and also a reduction in CO concentration at these conditions. The decrease in NO_x was a result of the lower primary zone temperature, but the reduction in CO was because of its reaction with the hydroxide ion (OH^-) created from the added water. This water injection technique may be useful as an interim abatement method, but it does not appear practical for use on a helicopter installation. The reduced burner exit temperature resulting from the addition of the water must be corrected

TABLE XV. VARIABLE-GEOMETRY NONREGENERATIVE T63-A-5A COMBUSTOR FLOW SPLITS USED IN REACTION KINETICS ANALYSIS

	CYCLE POINT				
	1	5	4	3	2
Power Level (%)	10	40	55	75	100
Flow Splits (%)					
Section I	26.9	32.3	42.9	49.1	74.4
Section II	12.8	12.8	12.8	12.8	12.8
Section III	17.4	17.4	17.4	11.4	.0
Section IV	42.9	37.5	26.9	26.7	12.8
Primary Zone Equivalence Ratio					
Fixed Geometry (Conventional)	.42	.51	.56	.64	.77
Variable Geometry	.60	.60	.50	.50	.39

back to standard burner exit temperatures by the addition of more fuel. Therefore, if exit temperatures are maintained by an increase in fuel flow, the predicted emissions would change accordingly.

Increased Length

The extended-length liner was a standard T63-A-5A liner with a 6-inch cylindrical section added between the first row of holes and the second cooling air annulus. The predicted emission changes from the standard liner agreed quite well with the changes in emissions observed in the test data. With this extended-length-liner design, the CO is reduced significantly enough that if it were coupled with a concept for reducing NO_x, the result might be quite favorable.

Double Combustor Volumes

If all of the combustor volumes were doubled, the CO concentration was predicted to decrease and the NO_x to increase. Since it is not desired to allow increases in NO_x, the size of the primary zone should not be increased. This was shown more positively in the early quench configuration presented above.

Doubled Predilution Volume, ϕ = .68

In this concept the predilution volume was increased in a standard length combustor by moving the second row of holes to the location of the third row, and moving the third row downstream to the end of the liner. If this were done to a standard liner, it was predicted that the CO concentrations would be reduced substantially at the low power conditions, while the NO_x hardly increased. Therefore, the downstream portion of the combustor has almost no effect on NO_x while permitting substantial changes in the CO concentrations. In this design the predilution volume was essentially doubled in a standard liner length.

Doubled Predilution Volume, ϕ = .50

This doubled predilution volume design had the same hole locations as the previous design, but the hole sizes were changed to lean the primary zone to reduce NO_x. The predicted emissions showed a significant decrease in NO_x, but the CO concentration increased to a level above the baseline concentration. It appeared that the T63 combustor CO emissions were very sensitive to equivalence ratio at the idle or 10% power operating conditions, but that at the higher power levels, the CO sensitivity was almost nonexistent.

Rapid Plug Flow

Figure 3 shows the importance of quickly reaching plug flow on reducing CO emissions. In the reaction kinetics model being used in this study, plug flow was approximated by a finite number of stirred reactors in series. Thus the degree toward achieving actual plug flow was indicated by the number of series stirred reactors in a particular region. As the number of stirred reactors increased, the region more closely approached plug flow. Therefore, it was reasonable to expect considerable reductions in CO concentrations if a combustor design converted to plug flow more quickly in the sensitive region immediately downstream of the first row of holes.

The EI values computed and listed in Table XIV for the reaction kinetics predictions were converted to percentage changes relative to the predicted baseline EI values in the analysis summary of Table XVI. From these kinetics studies, three of the Task 2 conclusions were supported: the primary zone should be small and should approach a stirred reactor kinetically, the predilution zone should convert to a plug flow region as quickly as possible, and variable geometry may reduce further the emissions of any fixed-geometry combustor.

Empirical Correlation Analyses

Exhaust emissions for the T63 gas turbine have successfully been predicted from empirically derived correlation equations.[13,14] The forms of these equations were employed along with normal least-squares curve fitting techniques to create a pair of empirical equations for predicting carbon monoxide and total oxides of nitrogen exhaust emissions from T63 combustors. The empirical equations were fitted to the standard T63-A-5A combustor emissions measured in the Research Laboratory on the T63 combustor rig which was set to the nonregenerative T63 operating conditions corresponding to the approved LOH mission duty cycle. The fitted expressions for CO and NO_x which were obtained are the following:

$$CO = 5219.*EXP(-.1511*10^{-7}*(P*T_f)^{1.25}*V/M) \quad (5)$$

$$NO_x = .5330*P*V/(M*T_f)*EXP(.001446*T_f) \quad (6)$$

where

CO = exhaust concentration of carbon monoxide, ppm

NO_x = exhaust concentration of total oxides of nitrogen, ppm

TABLE XVI. EMISSIONS ABATEMENT COMBUSTOR CONCEPT COMPARISON
ANALYSIS SUMMARY

NO.	COMBUSTOR CONCEPT DESCRIPTION	REACTION KINETICS - % EMISSIONS			EMPIRICAL CORRELATION - % EMISSIONS			PUBLISHED TEST DATA - % EMISSIONS		
		CO	NO_x	$CO+NO_x$	CO	NO_x	$CO+NO_x$	CO	NO_x	REFERENCES
0	BASELINE T63 (ø = .68)	100	100	100	100	100	100	100	100	-
	FUEL INJECTOR									
1a	Air Blast	-	-	-	-	-	-	122	95	-
1b	Air Assist	-	-	-	-	-	-	70	-	22,23,24
2	Premix and Vaporizer	-	-	-	-	-	-	-	60	18,23
3	Staged	-	-	-	-	-	-	30	52	15,25
	PRIMARY ZONE									
4a	Lean (ø = .35)	-	-	-	244	37	218	100	76	19,20,28,29
4b	(ø = .5)	412	17	255	163	58	148	-	-	-
5a	Rich (ø = 1.0)	49	1000	425	46	231	73	65	110	-
5b	(ø = 1.2)	-	-	-	-	-	-	100	55	19,20
6	Variable Geometry (ø = Variable)	51	66	57	86	100	88	300/33	33/300	16
7a	Early Quench (ø = .68)	65	65	65	100	100	100	300	55	18,19,20,25
7b	(ø = .35)	-	-	-	-	-	-	273	61	19,20
8	Reverse Flow	-	-	-	-	-	-	500	32	17,18,20
9	Massive Recirculation	-	-	-	-	-	-	235	21	16,17
10	Swirl	-	-	-	-	-	-	500	35	17,18,21,22,30
11	Heat Rejection	912	6	553	186	52	167	170	63	16
12	Water Injection	96	32	70	-	-	-	100	40	18,26,27,28
13	Cold Air Injection	-	-	-	-	-	-	-	70	18,28
	PRIMARY-DILUTION ZONE									
14a	Increased Length (+100%)	-	-	-	31	150	48	-	115	20
14b	(+200%)	[illegible]	110	57	7	216	37	32	140	-
15	Double Combustor Volumes	[illegible]	161	77	17	202	45	-	-	-
16a	Double Length (ø = .68)	52	104	72	18	194	45	-	-	-
16b	(ø = .5)	252	17	159	27	113	41	-	-	-
17	Rapid Plug Flow	58	100	64	-	-	-	-	-	-

P = combustor inlet pressure, psia

M = combustor overall airflow, lb/sec

V = combustor predilution volume, in^3

T_f = average flame temperature, °R

The T63-A-5A standard combustion liner is shown in Figure 6. The primary zone volume and flow fraction were used in the estimation of the average flame temperature. The degree of fit provided by the above empirical correlation equations can be seen in their comparison with the experimental rig data in Figure 7. These equations were used for the empirical correlation analyses of all applicable combustor concepts in the Task 2 evaluations.

The combustor concepts analyzed with the empirical correlation equations are listed in the summary chart of Table XVII, along with the emissions index computed for the CO and NO_x constituents over the LOH duty cycle. In general, the combustor concepts analyzed with the empirical correlation equations were the same concepts analyzed by the reaction kinetics approach.

Lean Primary Zone

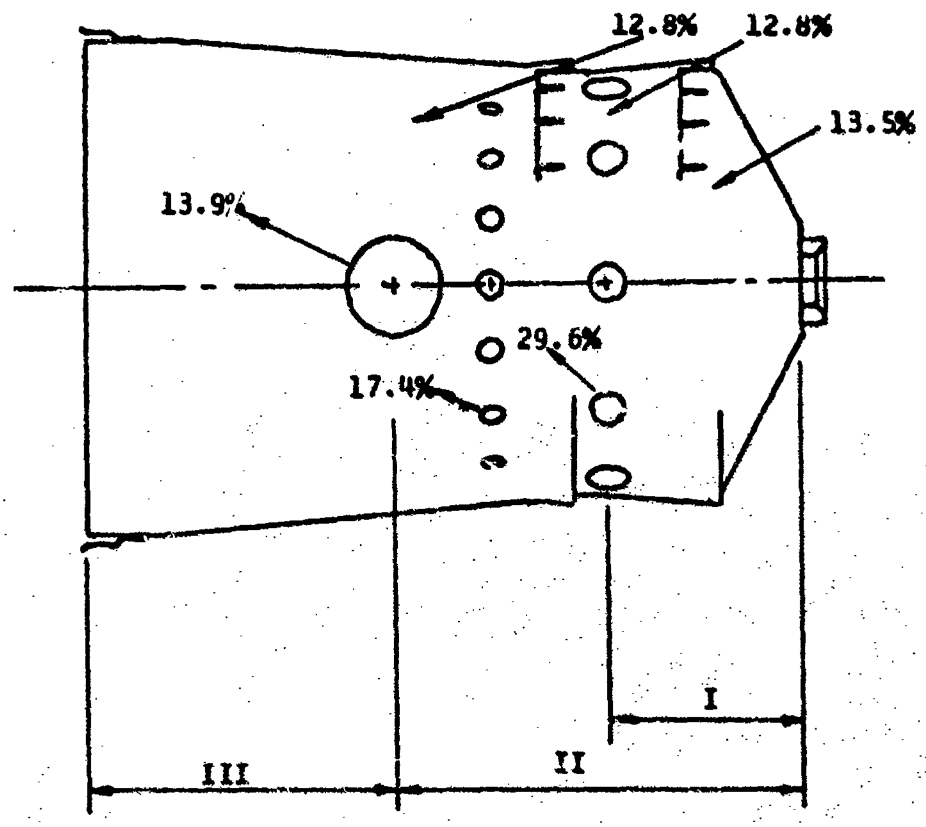
Emissions were predicted for two lean primary-zone combustion liners having primary-zone equivalence ratios of 0.35 and 0.50 at maximum power conditions. It was clear from the predicted emissions that the NO_x concentrations should be significantly reduced but that the CO increases to concentrations considerably above the baseline levels.

Rich Primary Zone

Enriching the primary zone reduced the CO concentration according to the empirical correlation model, but again at the expense of increasing the other constituent, NO_x. Therefore, as with the lean primary-zone configuration, changing the primary-zone equivalence ratio simply trades one emission for another.

Variable Geometry

A variable-geometry combustor has the potential of operating over a wide range of primary-zone equivalence ratios at any set of operating conditions. This concept was utilized in an approximate manner by computing CO and NO_x exhaust emission concentrations at each LOH operating point for primary equivalence ratios between 0.3 and 1.0. Using these predicted emissions, the time-weighted masses of each pollutant were computed for each



Section	Volume (in.^{3})	Flow Fraction Zone	Flow Fraction Total
I - Primary	43.3*	43.1%	43.1%
II - Predilution	106.7	74.3%	74.3%
III - Dilution	113.0	26.7%	100.0%
	219.7		

* Primary volume is included in predilution volume.

Figure 6. Empirical Correlation Combustor Model for Conventional T63-A-5A Combustor Liner.

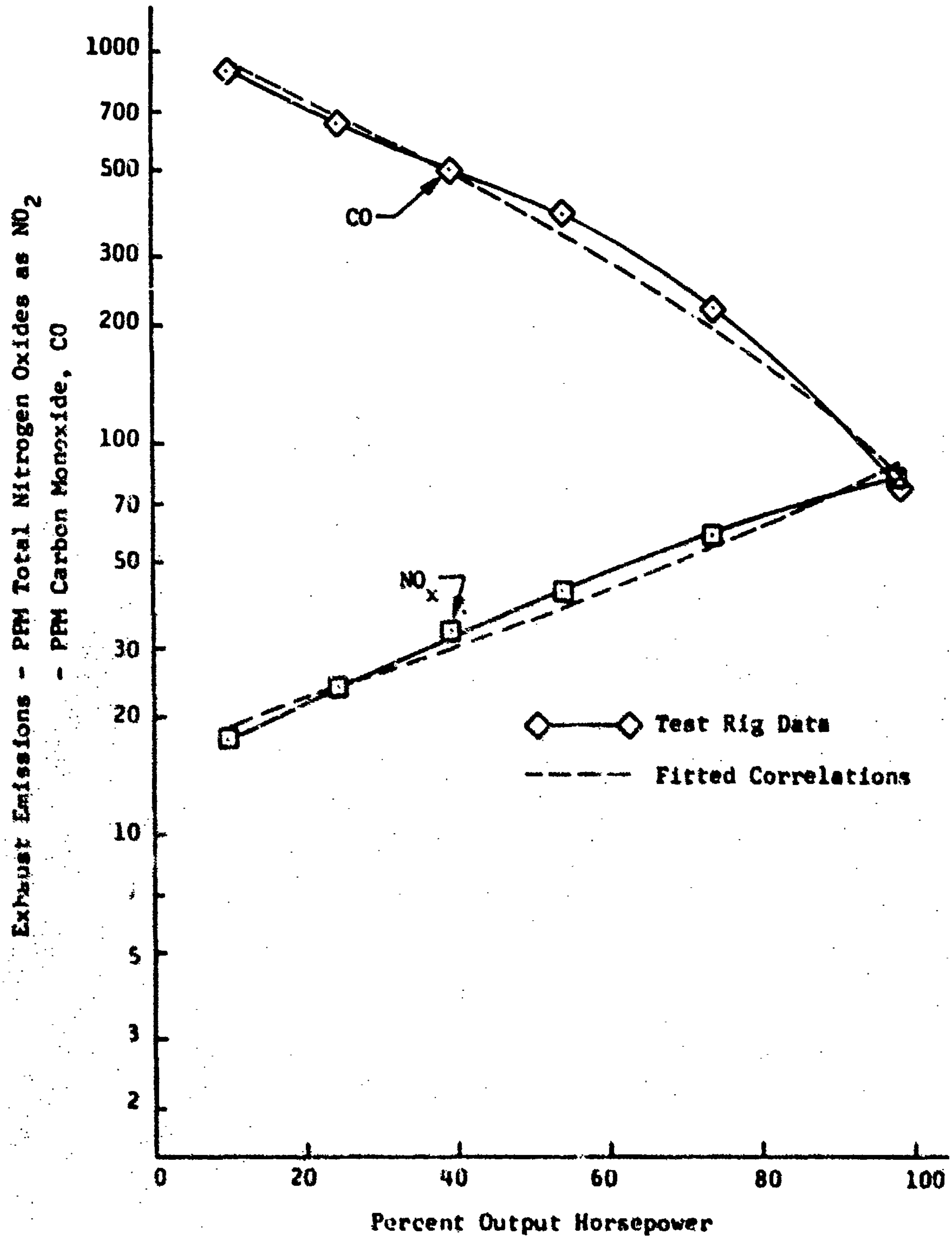


Figure 7. Fitted Empirical Correlation and Test Rig Emission for T63-A-5A Combustor.

TABLE XVII. EMISSION ABATEMENT COMBUSTOR CONCEPT COMPARISON - EMPIRICAL CORRELATION ANALYSIS

COMBUSTOR CONCEPT		EMISSION INDEX LB EMISSIONS/1000LB FUEL		
NO.	DESCRIPTION	CO	NO_x	$CO + NO_x$
00	Baseline T63 (Rig Test)	26.094	4.648	30.742
0	(Prediction)	25.978	4.331	30.309
	PRIMARY ZONE			
4a	Lean (ϕ = .35)	63.386	1.602	64.988
4b	(ϕ = .50)	42.310	2.522	44.832
5a	Rich (ϕ = 1.0)	12.034	10.000	22.034
6	Variable Geometry	22.354	4.326	26.680
7a	Early Quench	25.985	4.330	30.315
11	Heat Rejection	48.374	2.263	50.637
12	Water Injection	-	-	-
	PRIMARY-DILUTION ZONE			
14a	Increased Length (+100%)	8.053	6.496	14.549
14b	(+200%)	1.852	9.352	11.204
15	Double Combustor Volumes	4.398	8.758	13.156
16a	Double Length (ϕ = .68)	4.706	8.394	13.100
16b	(ϕ = .5)	7.024	4.882	11.906
17	Rapid Plugged Flow	-	-	-

duty cycle point. Emission indexes (EI), were computed for all of the possible combinations (5^8) of cycle point equivalence ratios. The minimum EI was then selected for two separate conditions. First there were no constraints imposed to limit any constituent EI. This effectively allowed for increased NO_x to be traded for decreased CO concentrations, as long as the combined EI was reduced. The resulting minimum EI for the case with no constraints imposed was 19.71 lb CO and NO_x emissions/1000 lb fuel compared with 30.31 lb CO and NO_x emissions/1000 lb fuel for the baseline combustor. The CO and NO_x concentrations are defined in Figures 8 and 9. for this case. Operating the combustor at these equivalence ratios allowed the oxides of nitrogen to more than double.

If the constraint were imposed that no cycle EI could exceed the standard combustor levels, a significantly different set of equivalence ratios resulted. These, the emissions concentrations corresponding to the "constrained" minimum cycle EI are also identified in Figures 8 and 9 . The NO_x emissions index was maintained at the baseline level, thus restricting the available CO reduction. The minimum EI for this "constrained" case was 26.68 lb CO and NO_x emissions/1000 lb fuel. This concept by itself, does not offer a solution to the goal of 50% emissions reduction, but it may be beneficial in combination with other techniques.

Early Quench

The empirical correlation equations are insensitive to changes in primary zone volume. Therefore, there was no effect predicted for an early quench primary zone combustor. Evaluations of this concept must be made by utilizing reaction kinetics and test data emissions.

Heat Rejection

In the empirical equations, heat rejection from the primary zone was approximated by reducing the primary-zone temperature by increments of -300°R. The predicted effect of heat rejection is the same as the effect shown for a more lean primary-zone combustor. The CO concentrations all increased and the NO_x concentrations all decreased. The EI in Table XVII for heat rejection were computed from the emissions concentration predicted by a 600°F reduction in primary zone temperature. To meet the goals of this contract, neither the CO nor the NO_x emissions can exceed those produced by the standard combustor.

Increased Length (Extended-Length Liner)

Since in the T63 combustor, carbon monoxide accounts for nearly 80% of the total mass emissions, significant effort should be

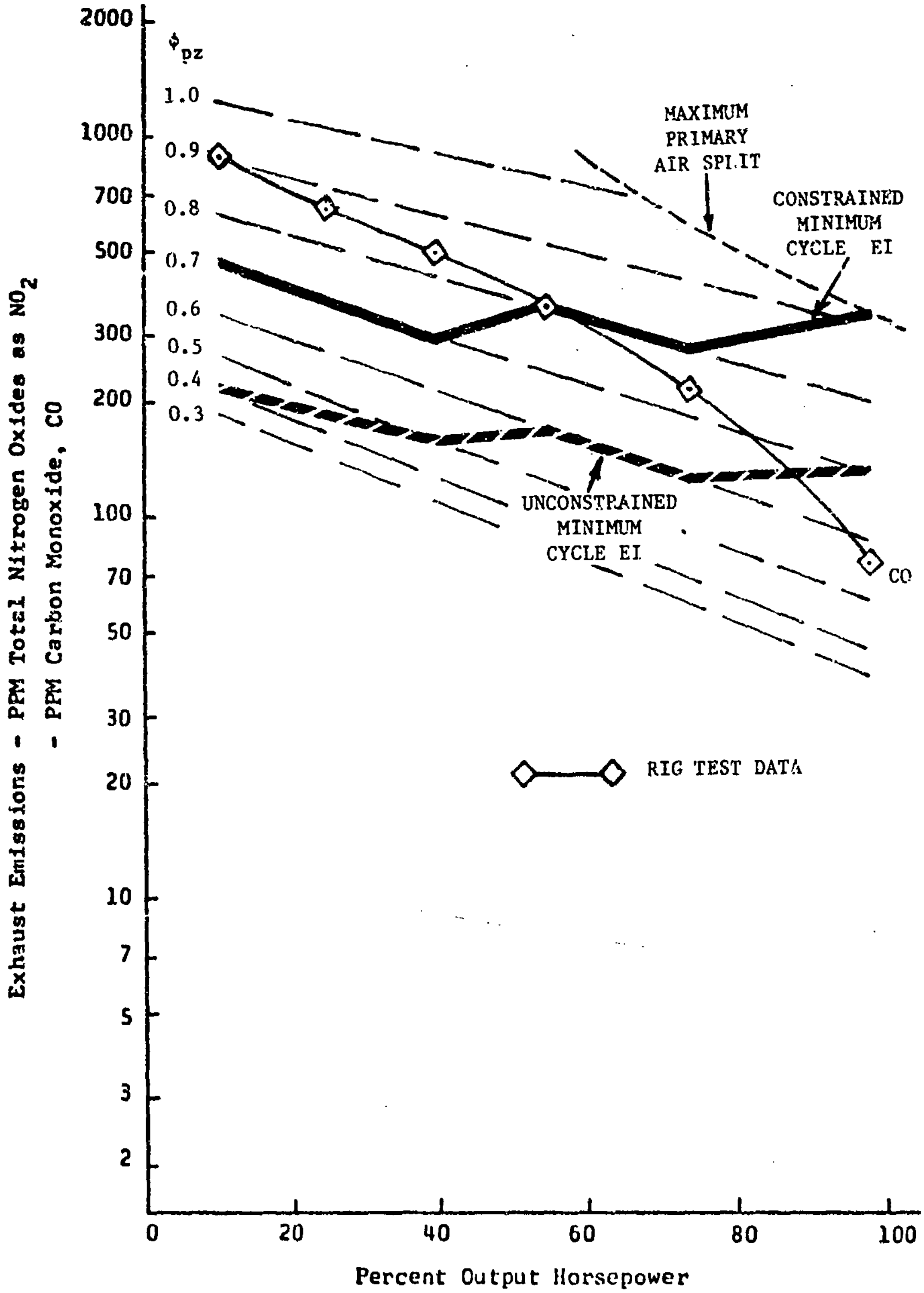


Figure 8. Empirical Correlation Predicted Variable-Geometry Emission Map for Carbon Monoxide.

duty cycle point. Emission indexes (EI), were computed for all of the possible combinations (5^8) of cycle point equivalence ratios. The minimum EI was then selected for two separate conditions. First there were no constraints imposed to limit any constituent EI. This effectively allowed for increased NO_x to be traded for decreased CO concentrations, as long as the combined EI was reduced. The resulting minimum EI for the case with no constraints imposed was 19.71 lb CO and NO_x emissions/1000 lb fuel compared with 30.31 lb CO and NO_x emissions/1000 lb fuel for the baseline combustor. The CO and NO_x concentrations are defined in Figures 8 and 9. for this case. Operating the combustor at these equivalence ratios allowed the oxides of nitrogen to more than double.

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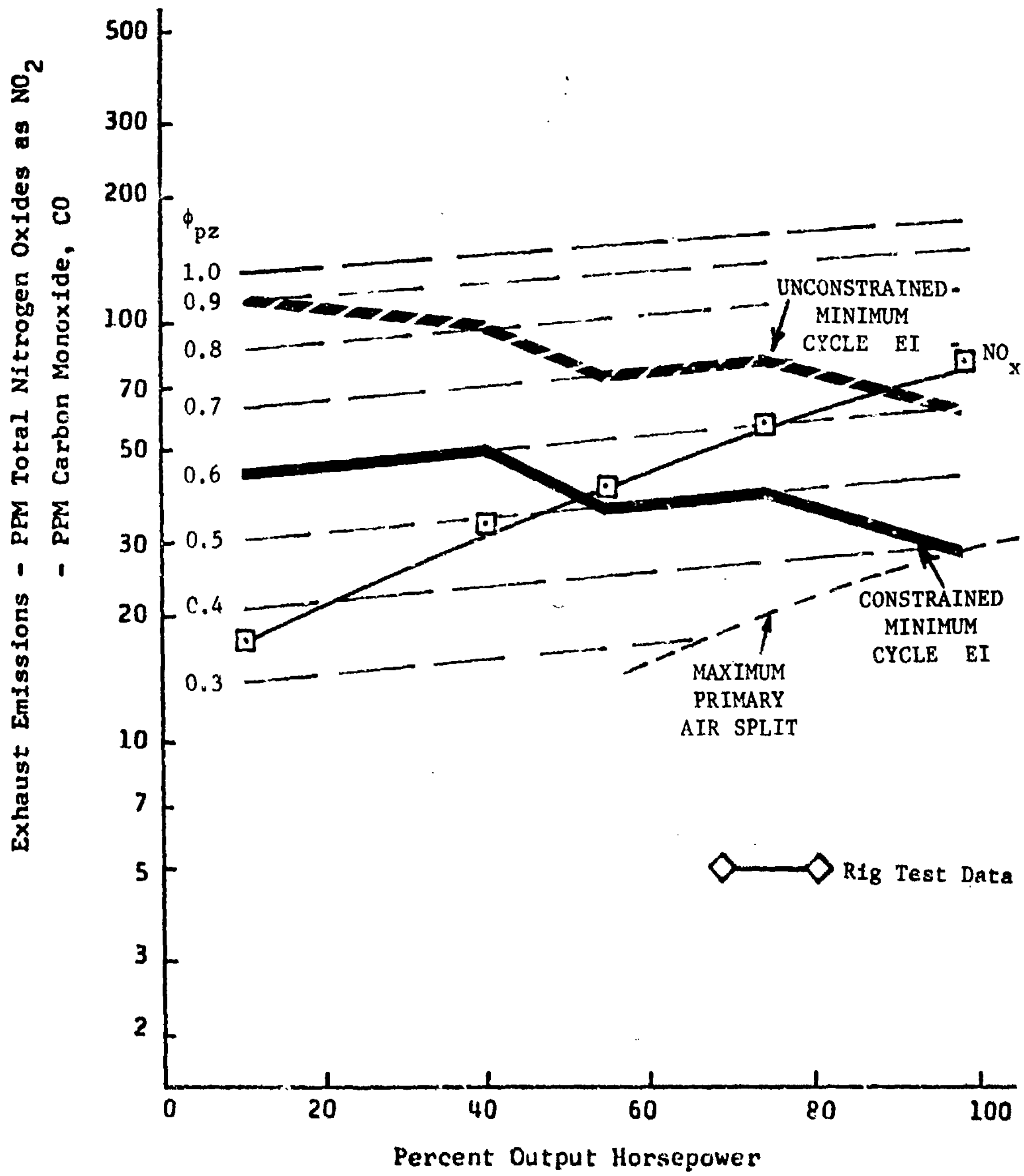

Figure 9. Empirical Correlation Predicted Variable-Geometry Emission Map for Oxides of Nitrogen.

directed toward reducing the CO exhaust emissions. One method for reducing the CO concentrations is to increase the residence time that the CO is within an oxidizable temperature range, thus allowing it to convert to CO_2.

This can be accomplished by increasing the predilution zone volume, viz., the region between the primary holes and the dilution holes. If this volume were increased 100% or 200%, the CO emissions should reduce substantially while the NO_x emissions should increase. The computed EI values using these predicted emissions show that the CO reduces at a much faster rate than the NO_x increases. Based upon these predictions, an extended-length liner was fabricated by adding a 6-inch cylindrical section to a standard liner to increase the predilution volume.

The significant reductions in CO from the increased predilution volume of the extended-length liner may permit tradeoffs with NO_x to reduce the NO_x back to baseline levels and thus achieve reasonable overall reductions in the total T63 combustor exhaust emissions.

Double Combustor Volumes

In this concept the entire combustor was doubled in volume. Here again, the empirical equations' insensitivity to the primary-zone volume showed less of an increase in NO_x emissions than would be realized in an experimental test. Because the total volume up to the dilution holes, when doubled, was nearly the same as a 200% increase in the volume between the primary and dilution holes, the emissions computed for the doubled-volume combustor were very close to the predicted emissions for the extended liner discussed above.

Double Predilution Length

If the dilution holes in a standard liner were moved downstream until the new combustor volume upstream of the dilution holes were twice the upstream volume in a standard combustor, the resulting emissions predicted by the empirical equations would have the same trends as discussed above for the standard equivalence-ratio-configuration, increased-volume combustors. Once again the CO was greatly reduced, but the NO_x increased. If the primary zone of this increased-length configuration were to operate at a more lean condition ($\phi = 0.50$), then the NO_x concentrations might be returned to standard emissions levels and a net CO reduction might still result.

Increased Volume/Variable Geometry

If a liner with increased predilution volume (here defined as the volume upstream of the dilution holes) were used to reduce the CO concentration, the NO_x emissions would increase. A plot of the computed LOH mission duty cycle EI as a function of predilution increase can be seen in Figure 10. The proportionate reduction in CO is predicted to be much greater than the increase in the NO_x emissions index. Applying variable geometry to some increased-volume combustor would allow a tradeoff between CO and NO_x, such that NO_x might be reduced to the baseline level while allowing CO to increase to a level above that predicted for the fixed-geometry larger-volume configuration. The result of this approach would be a net reduction in CO with no increase in NO_x. The predicted effects of this technique, using the empirical correlation equations, showed that the increased-volume/variable-geometry combustor concept may have the potential of meeting the emissions reduction contract goal of a 50% decrease in total emissions with no increase in any constituent emission.

Test Data

The sources of test data used in the analysis and selection of recommended concepts were from three general areas: combustor tests performed during the early portion of Task 3, combustor emission test results from General Motors divisions (DDA and GMR), and emission data from private industry outside General Motors and from Government agencies. The following sections will briefly discuss the types of test data obtained and how they were applied to the concept analyses of Task 2.

Rig Test Data

The first source of test data was the testing of three preliminary low-emission combustor concepts in Task 3 prior to the completion of Task 2. These three experimental tests were recommended early because of their simplicity and availability and because their test results would be very influential in the decisions relative to additional preliminary low-emission combustor concepts. These three combustor concepts were the following:

- Extended-Length Liner (Concept 1)
- Rich-Primary-Zone Liner (Concept 2)
- Air-Blast/Air-Assist Injector Liner (Concept 3)

The performance of these combustors is described in detail in the Task 3 discussion and in Appendix II.

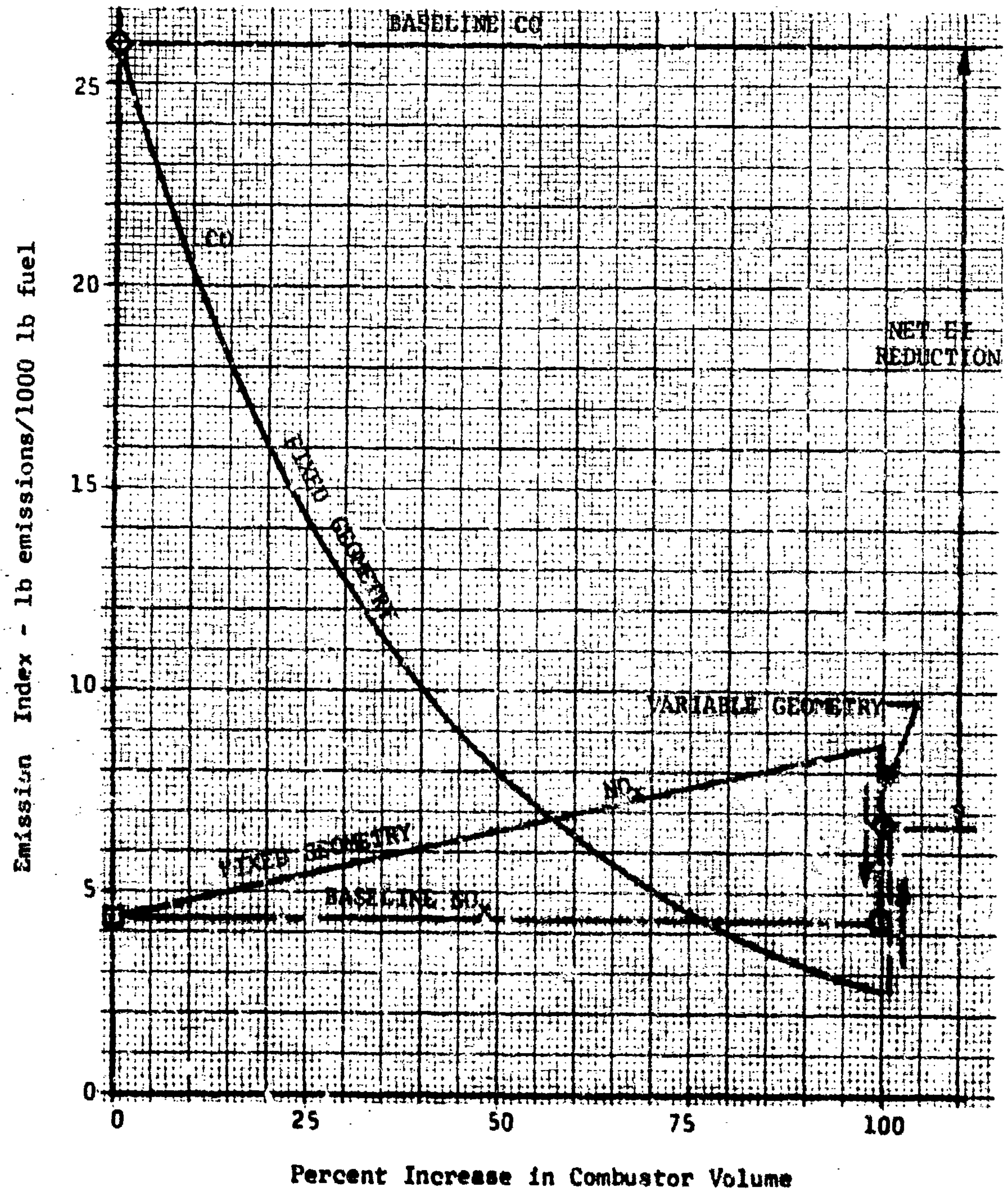

Figure 10. Predicted Nonregenerative Combustor Emissions, Effect of Increased Volume Plus Variable Geometry.

General Motors Test Data

The General Motors test data were obtained from two divisions of GMC. The Detroit Diesel Allison test data were both for aircraft combustors (T56 and T63 engines),[15] and for automotive combustor applications[16]. The remaining GMC sources were combustor development reports from General Motors Research Laboratories (GMR). One report[17] was concerned with reduced-emission combustors for Stirling engines. For these combustors, the reductions of all emissions (CO, C_xH_x, NO_x, and smoke) were measured and reported. The bulk of the GMR combustor experiments[18,19,20,21] were directed toward reducing the oxides of nitrogen in a regenerative gas turbine engine for automotive applications, the GT-309 engine. Data on NO_x concentrations were reported on all of the combustor designs either as a function of gasifier speed or at one gasifier speed (normally 80% speed).

Typical of the single-data-point concept evaluations by GMR is the effect of water injection on NO_x emissions shown in Figure 11. Shown here is a reduction of 57.5% in NO_x by the addition of 1.5 lb water/lb fuel. The empirical correlation equation predicted a reduction in NO of 43.9%, assuming that the lower flame temperature due to the water addition behaved as would heat rejection from the primary zone.

Even though the oxides of nitrogen emissions were well documented, carbon monoxide and hydrocarbons were reported in only general terms for many combustor designs. Thus, most of the GMR data was used for evaluating NO_x reduction combustor concepts.

Other Test Data Sources

The balance of the test data applied to the Task 2 evaluations were emission abatement concepts for aircraft gas turbine combustors. Several of these sources[22,23,24,25] were concerned with air-assist fuel injector designs for reducing emissions, primarily smoke. Water or steam injection[26,27,28] has been investigated as a concept for reducing oxides of nitrogen concentrations. Lean primary-zone combustors[28,29] were found to produce less NO_x than combustors which operated nearer stoichiometric in the primary zone. Improved mixing in the primary zone from swirler configurations[22,30] also resulted in lower oxides of nitrogen concentrations in the engine exhaust.

As is evident from the above combustor configurations, little test data was found on concepts for reducing carbon monoxide or hydrocarbon emissions. The referenced test data were used

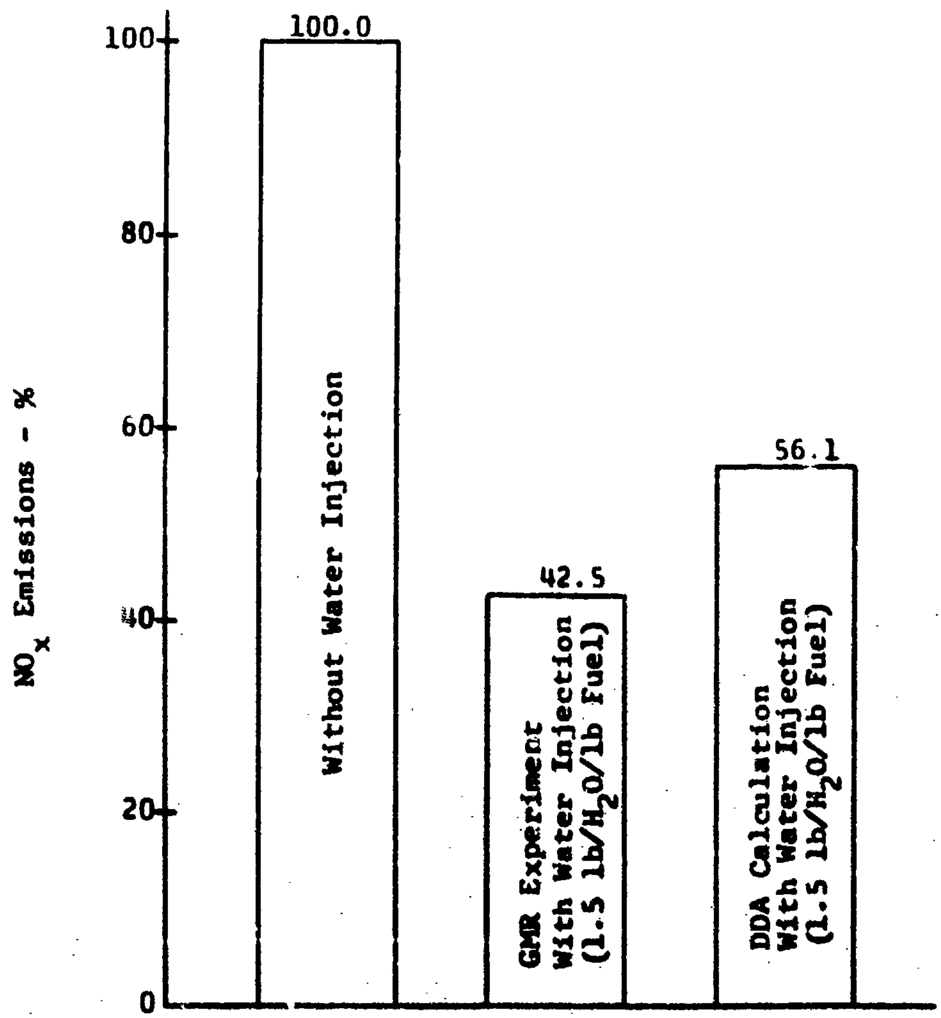

Figure 11. GMC GT-309 Combustor Design 112A - Water Injection Results.

in the summary chart on emission abatement concepts in Table XVI, page 33.

Because it was not possible to apply the test data directly to the LOH mission duty cycle, the effectiveness of the combustor concepts investigated was quantified on a percentage basis. Even though the combustor operating conditions were not the same as for the LOH cycle, combustor data presented as emission concentration as a function of gas generator speed were LOH duty cycle weighted at the corresponding percentage of gas generator speeds to compute an approximate emission index value for the concept. Whenever possible, emissions were converted to an emission index for both baseline and the abatement configurations, and the percentage change in each emission constituent was determined. The references listed in Table XVI refer to the reports listed in the literature cited section of this report.

Analysis Summary

The culmination of the Task 2 analysis of emission abatement combustor concepts is presented in Table XVI. In all, eighteen basic design concepts were analyzed for their emission reduction potential from three approaches: reaction kinetics, empirical correlation, and published test data. All concept emissions were translated from emission index to percentage change of carbon monoxide (CO) and oxides of nitrogen (NO_x) relative to the baseline combustor. For the reaction kinetics and empirical correlation analyses, the baseline combustor was the standard T63-A-5A combustor. For the published test data, a baseline combustor was the standard design from which the particular abatement concept was fabricated. The following comments concerning each of the emission abatement concepts summarize the results of the Task 2 investigation. The conclusions and the preliminary combusters were based upon these results. Refer to Table XVI for the numerical evaluations of each concept.

1. Air-Blast Fuel Injector

   The air-blast fuel injector tested had a more lean primary-zone than the standard injector. Thus, the CO increased somewhat. The most important contribution from this injector was the significant reduction in smoke or particulates.

2. Air-Assist Fuel Injector

   The air assist injector exhibited low smoke, as did the air blast injector. Some reductions in CO and C_xH_y were also obtained. It thus appears that an air-blast or air-assist fuel injector can be used to specifically reduce particulates and smoke and may provide some reductions in other emissions as well.

3. Premix and Vaporizer Systems

These systems show decreases in NO_x emissions which result from the better mixing of the air and fuel, thus reducing the local, fuel-rich hot-spot regions. Premixing and/or prevaporization of liquid fuel tends to bring the combustor primary zone closer to a stirred reactor region.

4. Staged Fuel Injection

Staged fuel systems are a compromise between a fixed-geometry and a variable-geometry combustor. These systems have multiple fuel injectors, and each operates over a more narrow range of primary-zone equivalence ratios than is possible with a single-injector, fixed-geometry combustor. If complexity such as staged fuel is acceptable, variable geometry should provide more control and lower emissions for no increase in complexity.

5. Lean Primary Zone

A more lean primary zone increases CO concentrations. Used by itself, this approach is unacceptable even though NO_x emissions are reduced. Where increases in CO can be traded for NO_x reductions, leaning the primary zone could be adapted.

6. Rich Primary Zone

Enrichening the primary zone increases the average flame temperature and thus the NO_x concentrations. Also, this approach tends to increase smoke and particulates.

7. Variable Geometry

Variable geometry can decrease both CO and NO_x averages over a duty cycle, but at the expense of increased complexity. It may be used on future fixed combustor designs to gain additional reductions in emissions.

8. Early-Quenched Primary Zone

An early-quenched primary zone may produce reductions in both CO and NO_x. Since the primary-zone volume is reduced, the residence time for NO_x formation is shorter. The intermediate zone between the primary and dilution zones is increased, thus allowing the CO to be further consumed. Earlier quenching, which implies a minimum-sized stirred-reactor primary zone, will reduce NO_x emissions.

9. Reverse-Flow Primary Zone

Reverse flow is a means of increasing the primary-zone mixing and recirculation. However, this concept may cause increases in CO emissions.

10. Massive Recirculation

This concept permits a tradeoff between CO and NO_x concentrations. The effect of massive exhaust recirculation is to reduce the NO_x by decreasing the local hot-zone temperatures and allowing leaner operation in the primary zone. A more lean primary, however, will create higher CO emissions. As the recirculation is increased, primary-zone conditions approach those of a stirred reactor. Thus the higher the recirculation, the smaller the required primary-zone volume.

11. Swirl Primary Zone

The effect of the swirl primary-zone concepts is to improve the mixedness and reduce the local hot-spot temperatures, thus reducing the concentrations of the NO_x formed. These designs also improve the primary-zone recirculation.

12. Heat Rejection

Heat rejection from the primary zone creates excessive increases in carbon monoxide. Also, a heat exchanger would be required between the primary zone and the dilution zone to transfer the heat. This heat exchanger would be large except for low heat rejection rates.

13. Water Injection

Although water injection into the primary zone will decrease CO and NO_x concentrations, its use may present logistics problems. In addition to the mass of water which must be carried, the use of water will require higher fuel usage to maintain turbine inlet temperature, and this will penalize the engine SFC as well as payload. Also, the engine cost and complexity will increase. Therefore, this approach should be considered only if other techniques are unsuccessful or as an interim emission reduction technique for existing aircraft.

14. Cold Air Injection

The injection of cold air into the primary zone has the most attractiveness for NO_x reduction in regenerative gas turbine engines which inherently have a source of cold air. For a nonregenerative engine, an auxiliary air compressor would be required as well as a heat exchanger to reduce the injected air temperature. Therefore, it appears that cold air injection is impractical for the standard T63 engine.

15. Increased Predilution Length (Extended-Length Liner)

The importance of increased predilution length was dramatically illustrated by the reductions in carbon monoxide, hydrocarbons, and smoke (particulates) in the extended-length-liner test. It appears practical to use the extended-length liner with its slightly higher NO_x emissions and to apply other techniques to reduce the NO_x. An extended-length liner in combination with early quench, for instance, may produce reductions in all emissions. Effort could then be directed at reducing the overall combustor length.

16. Double Combustor Volumes

The sizable increases in NO_x due to increases in the primary-zone volume clearly show that the primary zone must be reduced to as small a volume as possible.

17. Double Predilution Length

Doubling the predilution length within the standard combustor envelope should substantially reduce the CO emissions. The NO_x concentrations should increase and possibly the combustor exit temperature profile may be severely distorted. Improvements might be more lean operation to reduce the NO_x at the expense of increased CO, but the exit temperature profile may be the most important element in combustor performance acceptability

18. Rapid Plug Flow

The rapid conversion to plugged flow downstream of the primary zone should produce the largest reduction in CO per inch of predilution zone length. The attainment of rapid plug flow may provide significant CO reductions in a standard combustor envelope.

It appeared from the analyses conducted in Task 2 that to reach or exceed the 50% minimum total emissions reduction goal with no increase in any constituent emission product, a combination of two or more of the promising concepts investigated above might be required. Several of the preliminary combustor concepts for Task 3 testing incorporated combinations of emission abatement concepts. It was the testing of these preliminary concepts that gave direction to the remainder of this contractual effort.

Conclusions

The analyses conducted in Task 2 revealed four emission-abatement combustor design approaches which should be explored and evaluated in Task 3 testing:

1. Fuel injectors should be an air-blast or air-assist configuration. This type of fuel injector should have the most significant effect on reducing combustor exhaust mass particulates and smoke.

2. The combustor primary zone should be as small as possible and should approach a stirred reactor region kinetically. As combustors approach this goal, the carbon monoxide and oxides of nitrogen should be reduced.

3. The predilution zone (that region between the primary zone and the dilution zone) should convert to a plug flow region as quickly as possible. This approach should significantly reduce the carbon monoxide concentration with little effect on the oxides of nitrogen. This might be accomplished by geometrical changes to force early plug flow, or it might be sought by lengthening the predilution zone section of the combustor.

4. Emissions from any fixed-geometry combustor may be reduced further by the inclusion of variable geometry to control the air split between the primary and dilution zones, thus controlling the primary-zone equivalence ratio.

Preliminary Concepts

The conclusions from the Task 2 studies along with some early combustor testing from Task 3 have resulted in preliminary concepts to be fabricated and tested in Task 3. The following is a description of the preliminary emission-abatement concepts in the order of testing priority. It was anticipated that subsequent modifications to those concepts which demonstrate reductions in emissions might be required to fully evaluate their design potentials. Each of the subsequent concepts is, in general, a modified version of the stan-

dard T63-A-5A nonregenerative combustor sketched in Figures 4 and 6.

1. Extended-Length Liner (Figure 12)

The extended-length liner was a standard T63-A-5A liner with a 6-inch cylindrical section inserted between the first, or primary, row of holes and the second film-cooling air annulus. This additional predilution length would allow more residence time at intermediate combustion temperatures to consume the CO, unburned C_xH_y, and particulates before reaching the reaction-quenching dilution air. Even though an increase in NO_x was expected, this emission constituent problem would be dealt with by adapting NO_x reduction techniques to the extended-length hardware.

2. Rich-Primary-Zone, Standard-Length Liner (Figure 13)

The purpose of the rich-primary-zone combustor was to establish experimentally the tradeoff between CO and NO_x resulting from increased primary zone equivalence ratios. As the extended-length liner experimentally evaluated increased predilution residence time, the rich-primary-zone liner experimentally evaluated increased primary-zone reaction temperatures.

3. Air-Blast/Air-Assist Fuel Injector, Standard-Length Liner Figure 14)

Experimental data have shown that air-blast and air-assist fuel injectors greatly reduce the smoke or particulates produced by a combustor. The improved fuel spray preparation and mixing by the blast air were expected to assist in the suppression of primary-zone hot spots and localized quenching, thus potentially reducing both NO_x and CO. This fuel injector evaluation was tested in a conventional T63-A-5A liner with the fuel injector bushing modified as required to accept the fuel nozzles.

4. Variable-Geometry, Extended-Length Liner (Figure 15)

For this design the NO_x, increased by the longer residence time from the additional length, was to be controlled by variable dilution geometry. The variable geometry was accomplished by the rotation of a ring covering enlarged dilution holes, which increased or decreased the blockage to the dilution air. This combustor was designed to operate at primary-zone equivalence ratios above and below those in the standard liner. The second row of holes was closed, and additional holes were added in the dilution hole row. A

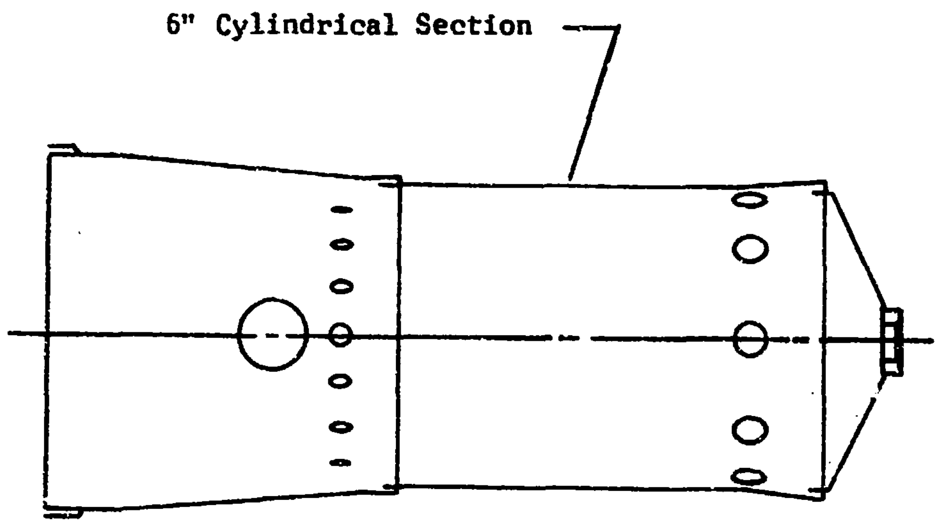

Figure 12. Extended-Length Preliminary Combustor Liner.

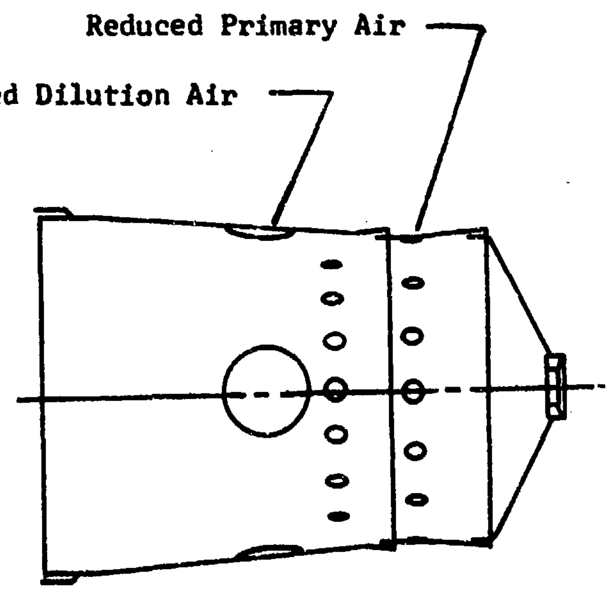

Figure 13. Rich-Primary-Zone, Standard-Length Preliminary Combustor Liner.

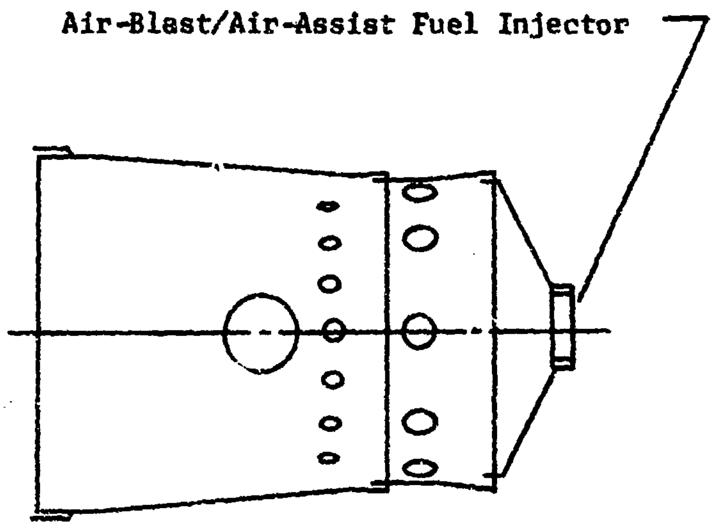

Figure 14. Air-Blast/Air-Assist Fuel Injector, Standard-Length Preliminary Combustor Liner.

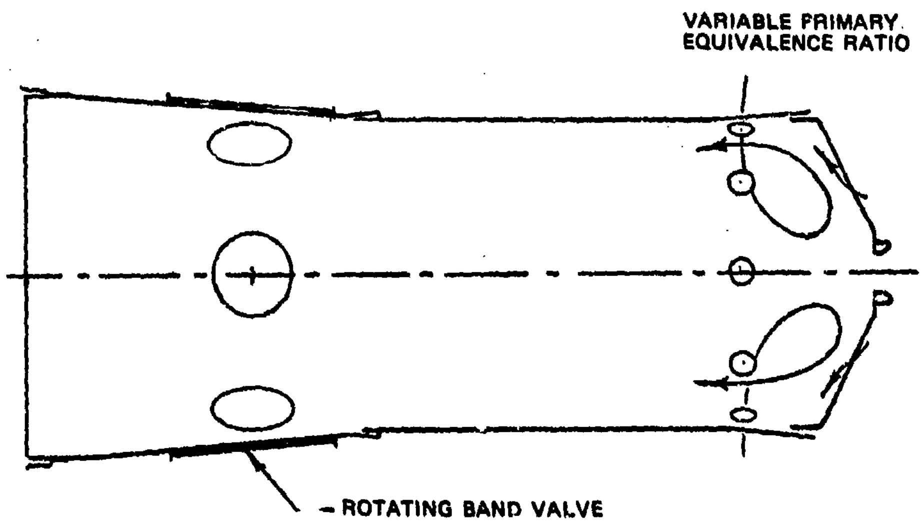

Figure 15. Variable-Geometry, Extended-Length Preliminary Combustor Liner.

standard fuel injector was used, and the liner dome remained unchanged.

5. Early-Quench, Extended-Length Liner (Figure 16)

Beginning with a basic extended length liner, the first row of holes was covered and an identical row was cut in the liner adjacent to the first cooling air annulus. This modification produced an early-quench primary zone which was to reduce the NO_x concentration in the combustor. A standard fuel injector was used.

6. Delayed-Dilution, Standard-Length Liner (Figure 17)

This liner and liner number 7 were the only modified standard-length liners recommended for preliminary testing. It was hoped that the length of a successful long liner could be reduced in the latter stages of this contract, but an early evaluation of a standard-length liner would show sensitivity of the combustor exhaust temperature profile to dilution hole geometry and dilution zone length. For this standard length design, the second and third rows of holes were closed, and a new dilution, row of holes was added further downstream just ahead of the exhaust centerbody as indicated. The fuel injector, dome, and first row of holes were standard.

7. Delayed-Dilution/Annular-Dilution Standard-Length Liner (Figure 18)

In anticipation of a degradation in exhaust temperature profile in Concept 6, an upstream extension to the combustor centerbody was added and the dilution holes were modified. There were more dilution holes of smaller size in this design. This created a single-sided annular dilution zone in the "can" type combustor. The concept was that single-sided dilution from a multiplicity of dilution holes would significantly improve the exhaust temperature pattern.

8. Premix-Cup/Gaseous-Fuel Extended-Length Liner (Figure 19)

For this design, the conventional dome was removed and a premix cup was attached in its place. The first row of holes was closed. Through the lateral sides of the premix cup passed the primary air previously added through the dome and first row of holes in the standard liner. All of the primary air was injected through a multiplicity of small holes, creating a "pepper pot" type of premixing of the fuel and air. The liner was extended length, with the extra length being added in the center section as in the baseline extended-length liner (Concept 1). Gaseous propane was the fuel injected

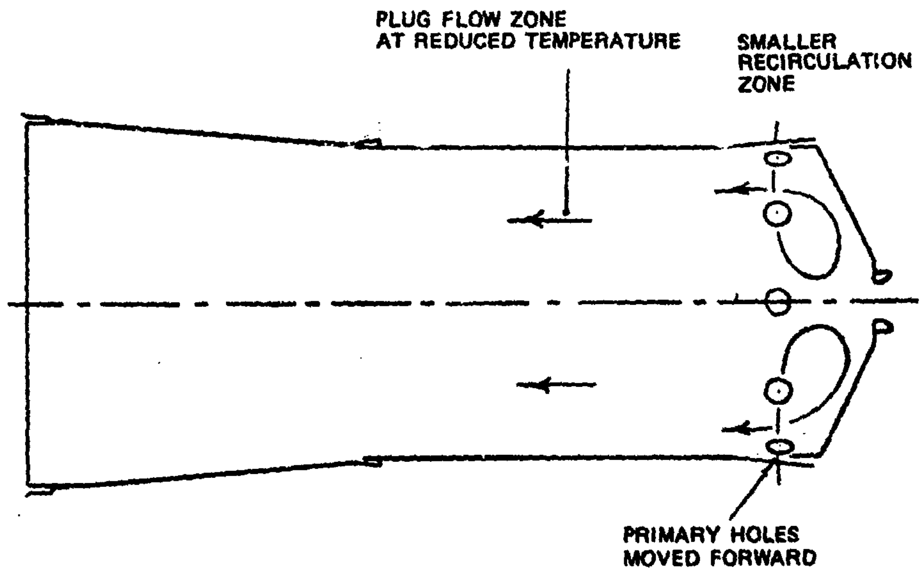

Figure 16. Early-Quench, Extended-Length Preliminary Combustor Liner.

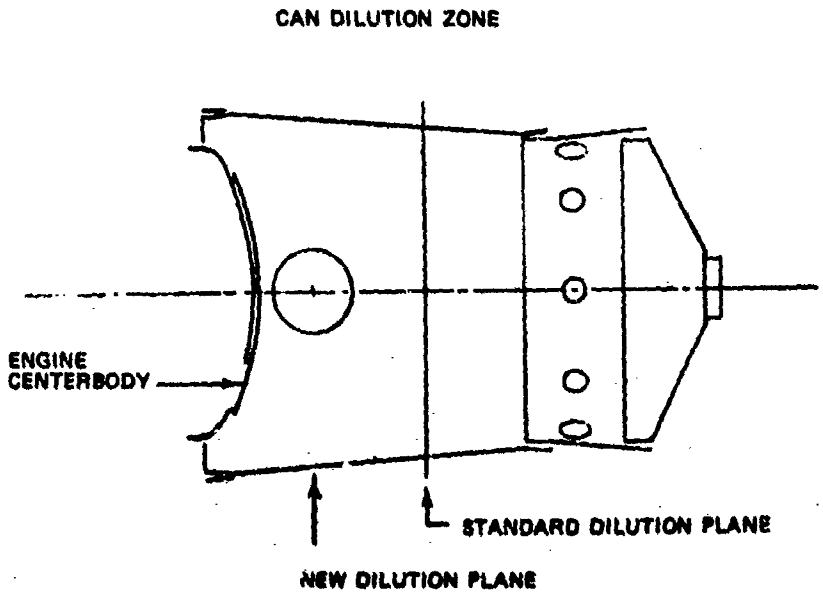

Figure 17. Delayed-Dilution, Standard-Length Preliminary Combustor Liner.

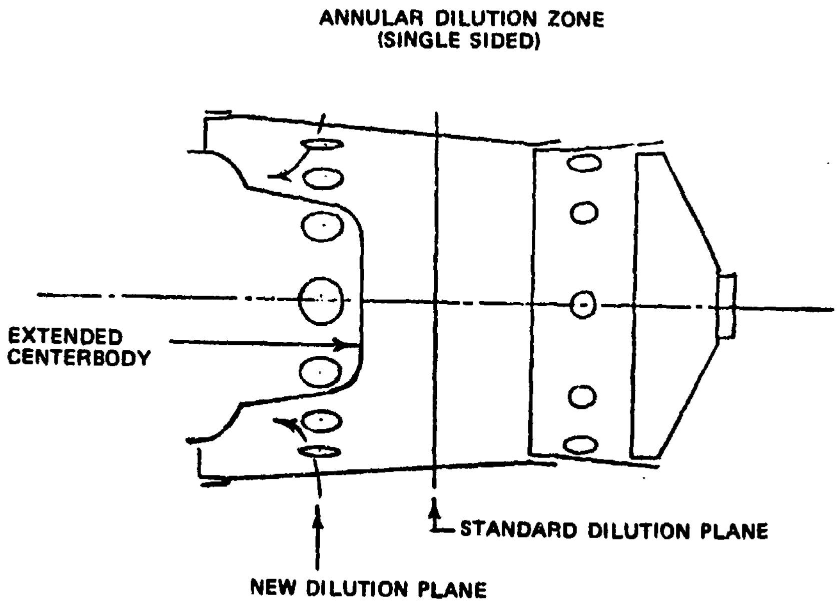

Figure 18. Delayed-Dilution/Annular-Dilution, Standard-Length Preliminary Combustor Liner.

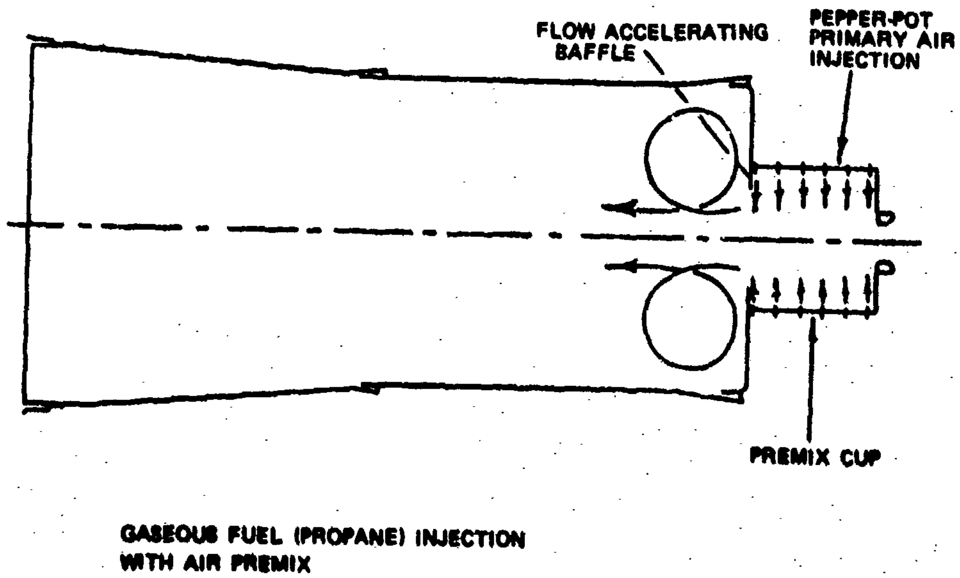

Figure 19. Premix-Cup/Gaseous-Fuel, Extended-Length Preliminary Combustor Liner.

into the premix cup to simulate prevaporized fuel. It was planned that, should this test demonstrate significant emission reduction, a liquid fuel vaporizer system would be designed and tested. A methane torch igniter was used to light the burner.

9. Plug-Flow/Canted-Primary-Air, Extended-Length Liner (Figure 20)

The predilution section of this combustor deviated considerably from the standard liner. The purpose of the converging section was to induce a plug flow region as far upstream as possible. This extended-length combustor maintained the standard fuel injector and dome, but the primary air holes were located on the canted surface of the predilution zone throat and thus injected the primary air in an upstream or reverse-flow direction. It was hoped that injecting the primary air in this manner would increase the primary-zone mixing.

10. Tangential-Swirl-Dome Extended-Length Liner (Figure 21)

In this design the liner dome was replaced with a tangential swirler through which passed all of the primary zone air. The first row of holes in the standard extended-length liner section was closed. The second and third rows of holes remained unchanged. A standard fuel injector was used. It was hoped that the tangential swirler would produce increased mixing and recirculation in the primary zone. This combustor had the same overall length as the standard extended-length liner: 6 inches longer than the production T63-A-5A liner.

11. Radial-Swirl, Primary-Zone, Extended-Length Liner (Figure 22)

This combustor was similar to the tangential-dome swirler configuration (Concept 10). It, too, was extended length with a standard injector, but instead of a tangential swirler, a radial swirler injecting the same volume of primary air was used.

12. Rich-Premix/Swirl-Dome, Extended-Length Liner (Figure 23)

This combustor configuration was an attempt to operate a combustor liner at above stoichiometric fuel-air mixtures in the primary zone to inhibit the formation of NO_x. This was accomplished by creating a fuel-rich swirl-stabilized mixture in a premix cup having a radial swirler concentric with the standard fuel injector. This rich mixture was stabilized by the sudden expansion at the entrance to the reaction zone and quenched by a row of holes

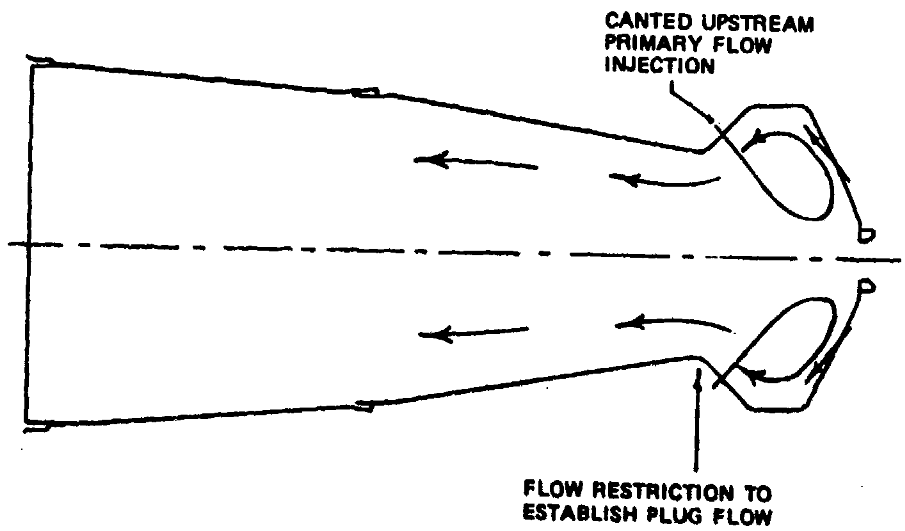

Figure 20. Plug-Flow/Canted-Primary, Extended-Length Preliminary Combustor Liner.

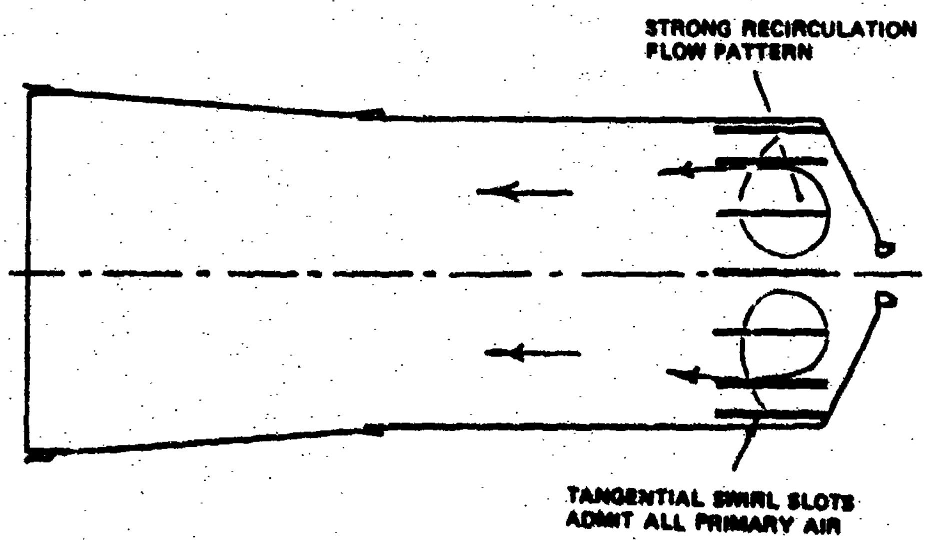

Figure 21. Tangential-Swirl, Extended-Length Preliminary Combustor Liner.

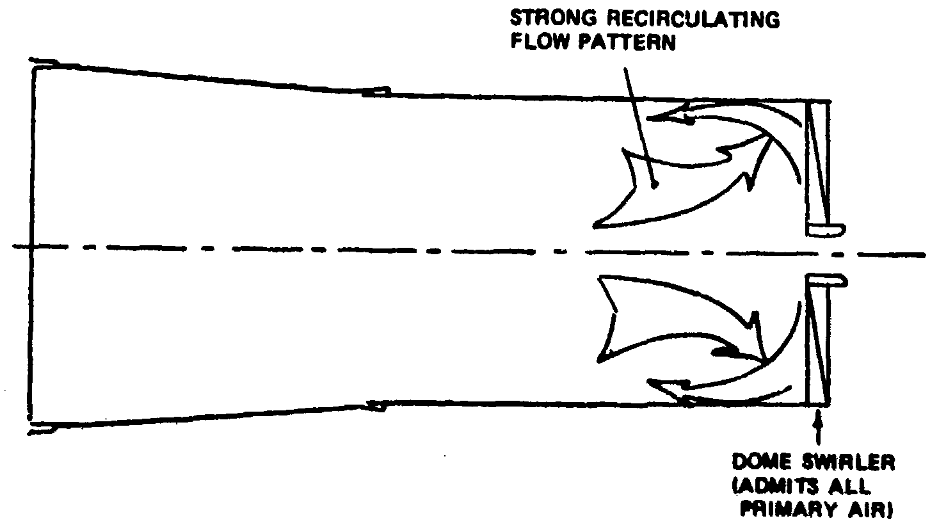

Figure 22. Radial-Swirl, Extended-Length Preliminary Combustor Liner.

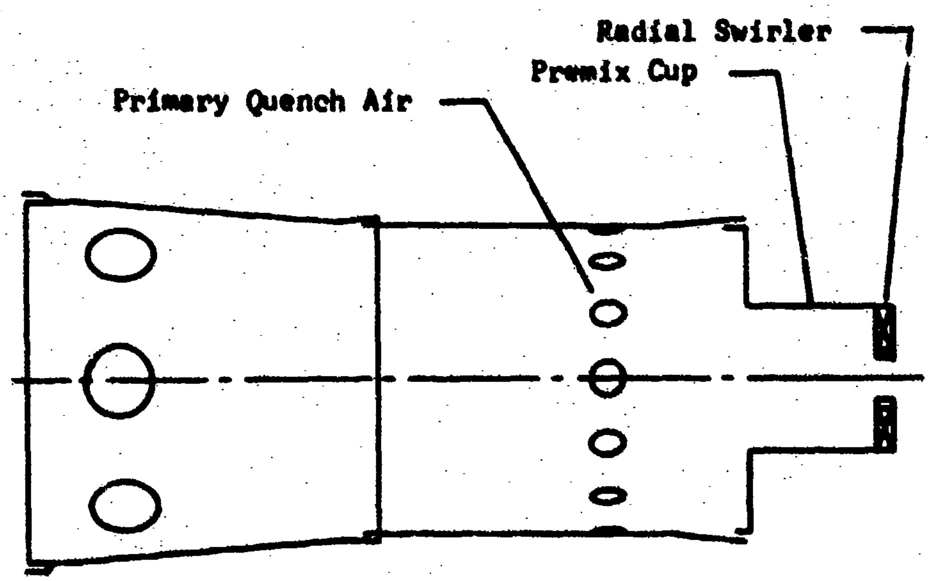

Figure 23. Rich-Premix/Swirl-Dome, Extended-Length Preliminary Combustor Liner.

located downstream of the reaction zone. The concept was that the fuel rich primary-zone would retard the NO_x formation and the sudden quench would quickly reduce the reaction temperature to a level below rapid NO_x formation temperatures. The extended length would consume the CO, C_xH_y, and particulates as before, resulting in reductions in all emissions.

13. Pepper-Pot-Dome, Extended-Length Liner (Figure 24)

The pepper-pot dome combustor was conceived to apply the conclusion that low NO_x would result from rapidly mixed, small-primary-zone recirculation. This approach was applied by designing the primary zone to have all of the inlet air enter through a multiplicity of small orifices in the liner dome. These orifices would induce short penetration jets into the liner through the fuel spray, forcing the reaction to occur in a small volume adjacent to the liner dome. Convection predilution zone cooling was used to avoid quenching the CO, C_xH_y, and particulate reactions in the extended-length combustor. A conventional fuel injector was used.

14. Delayed-Quench, Extended-Length Liner (Figure 25)

The delayed-quench combustor was a third version of a primary-hole axial location investigation which was searching for NO_x reduction by repositioning the axial location of the primary holes. The early quench (Concept 5) and the extended length (Concept 1) were identical combustors having different axial positions of the primary holes.

15. Premix/Prevaporization, Extended-Length Liner (Figure 26)

This combustor concept utilized a premix/prevaporization tube section upstream of the primary section to premix the fuel and primary air and to prevaporize the fuel before entering the reaction zone. This premix/prevaporization feature was to improve combustor homogeneity and to avoid fuel droplet burning in an extended-length combustor. Additional features of this concept were sudden expansion for flame stabilization, lean primary zone to minimize NO_x formation, delayed dilution to consume the CO, C_xH_y, and particulates, and convection cooling instead of film cooling to avoid quenching the CO, C_xH_y, and carbon reactions in the cool air film.

16. Prechamber Extended-Length Liner (Figure 27)

The fuel prevaporization approach was further explored with

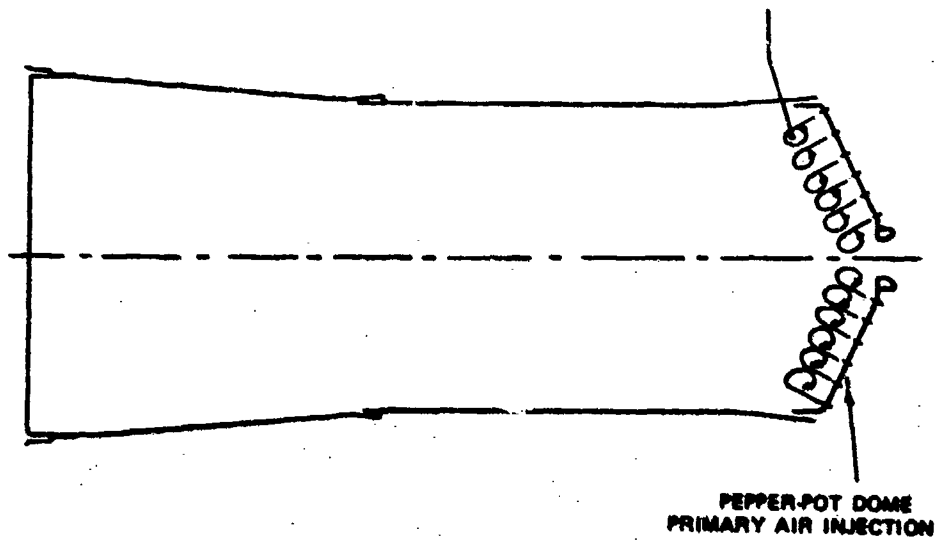

Figure 24. Pepper-Pot Dome, Extended-Length Preliminary Combustor Liner.

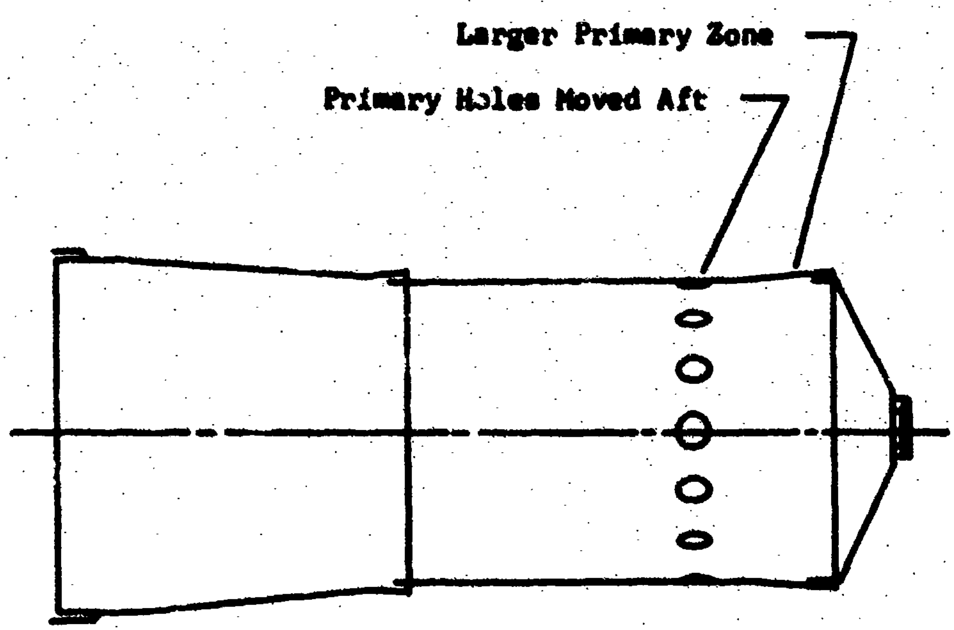

Figure 25. Delayed-Quench, Extended-Length Preliminary Combustor Liner.

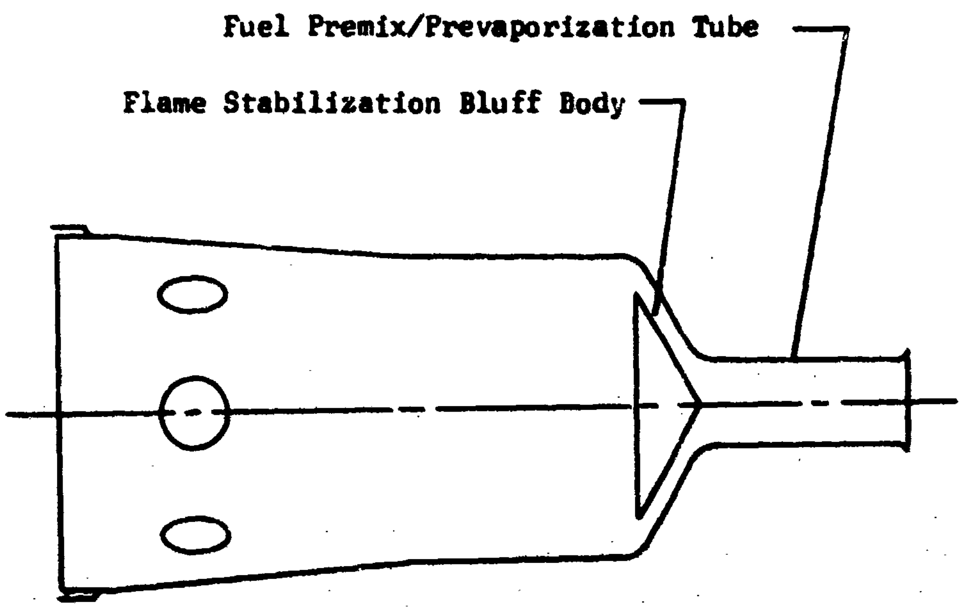

Figure 26. Premix/Prevaporization, Extended-Length Preliminary Combustor Liner.

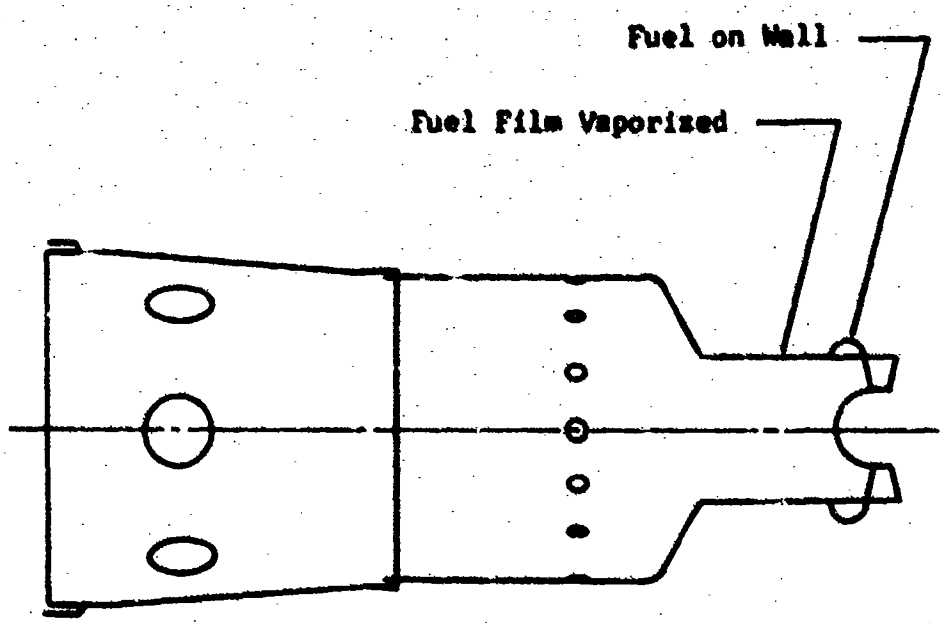

Figure 27. Prechamber, Extended-Length Preliminary Combustor Liner.

a different vaporization mechanism in the prechamber combustor. In this concept the fuel was vaporized off the inside surface of a premix tube. A high-velocity mixture of inlet air and combustion gases supplied the heat of vaporization to the fuel and mixed with the vaporized fuel prior to combustion. The homogeneity of the fuel-gas mixture was to reduce all emission constituents: the NO_x by the reaction zone design, and the CO, C_xH_y, and carbon by the extended length prior to dilution quench.

17. Optimum Primary, Extended-Length Liner (Figure 28)

A final primary hole design was investigated with the "optimum primary" concept. A six-hole pattern of primary boles in the conventional axial location replaced the standard twelve-hole pattern. The concept in this reduction in the number of primary holes for the same air input was that the larger jets of air would penetrate the primary zone more energetically, thus improving the mixedness and recirculation. The extended length was retained for consumption of the CO, NO_x, and carbon.

The majority of the recommended combustors were 6 inches longer than the standard T63-A-5A combustor. It was predicted in Task 2 that this added length could significantly reduce CO, C_xH_y, and smoke. Those designs described above which could maintain the reduced CO, C_xH_y, and smoke while reducing the NO_x were candidates for further design modifications to shorten the combustor liner as much as possible and still meet the emission reduction goals while not degrading the combustor pressure loss, stability or exit temperature profile. These decisions were made after the above preliminary concepts had been fabricated and tested.

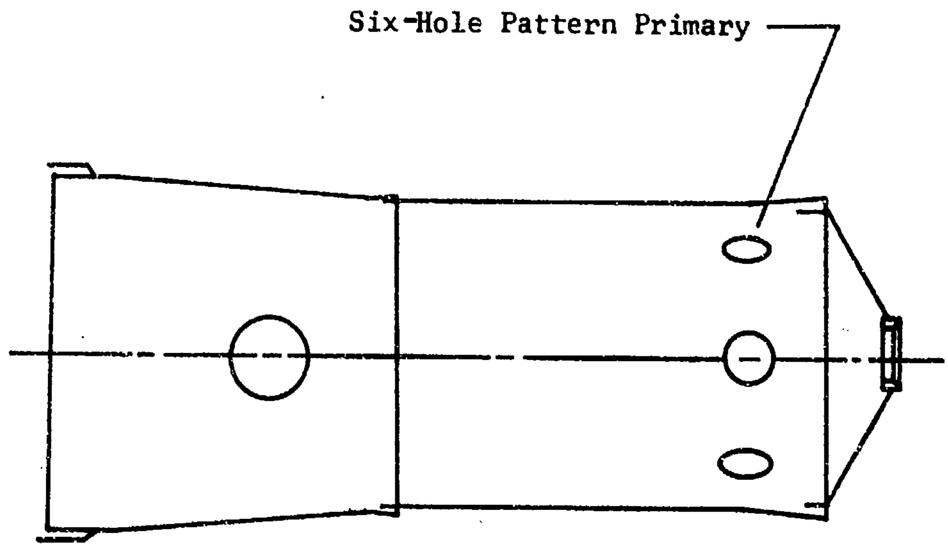

Figure 28. Optimum Primary, Extended-Length Preliminary Combustor Liner.

TASK 3 - TEST

The experimental testing phase of this program was to obtain experimental emission and combustor performance data in a combustor test rig which simulated the T63-A-5A gas turbine engine. The combustor rig testing accumulated 673 data points taken during 246:40 hours of burning time on 31 different combustors. The combustors tested were of three general types, listed below:

- Baseline T63-A-5A Combustors
  3 Tested

- Preliminary Low-Emission Combustors
  17 Tested

- Final Low-Emission Combustors
  11 Tested

  - Prechamber
    8 Tested

  - Modified Conventional
    3 Tested

The Task 3 results reported in this section are discussed in the four areas in which the work was performed:

- Experimental System Description - A description of the facility, instrumentation, and combustor test rig used.

- Baseline Combustor - A discussion of the T63 nonregenerative and regenerative combustor experiments conducted to establish baseline combustor emissions, and a correlation between combustor rig and available engine emissions data.

- Evaluation of Preliminary Combustors - A discussion of the design and test results from the seventeen preliminary low-emission combustor liners evaluated to assess one or more low-emission concepts.

- Evaluation of Final Combustors - A discussion of the design and test results from the eight "Prechamber" low-emission combustors and the three "Modified Conventional" low-emission combustors relative to their satisfying the objectives set forth for this combustor program.

Experimental System Description

The combustion experiments were conducted in the DDA Combustion Research Laboratory. In addition to the combustion experiments, some of the liners were tested in cold-flow air experiments. Both the cold-flow experimental system and the combustion experimental system are described in the following sections.

Cold-Flow Experimental System

The cold-flow experimental system provides qualitative data on the aerodynamic flow pattern in the combustor liners. It provides some insight into where the air goes after entering the combustor liner. As shown in Figure 29, the combustor liner is inserted into the plenum which is fed with air at ambient temperature and slightly above atmospheric pressure. The flow rate during the tests is set to simulate the actual flow factor,

$$\left(\frac{W_a \sqrt{T}}{P}\right)$$

which is encountered in hot-flow combustion experiments. A plate, coated with a mixture of kerosene and carbon black, contoured to the shape of the combustor is installed in the liner through the exit. The airflow rate is then established and maintained until the flow pattern is imprinted on the plate, as shown in Figure 30 for the T63-A-5A conventional combustor liner.

Although the cold-flow experiments were crude and provided only qualitative data, the results were valuable in assessing the aerodynamic flow patterns inside the combustor liners. Several of the low-emission combustor liner designs were modified based upon the cold-flow results. A more sophisticated instrumentation approach using hot wire anemometry has been used in the past to measure quantitatively the 3-D flow path, but this approach was beyond this program's scope. It is, however, recommended that such a system be computerized and used to establish the 3-D aerodynamic flow paths in combustor liners. Ideally, the tests should be conducted under actual combustion conditions, but the current hot-wire probes cannot withstand the temperature.

Combustion Experimental System

The combustion experiments were conducted in the DDA Combustion Research Laboratory using JP-4 fuel and nonvitiated (neat) air. The required combustor operating conditions were previously selected and established in Task 1. The combustor operating conditions, as previously presented in Tables IV and V, vary over the following range of conditions:

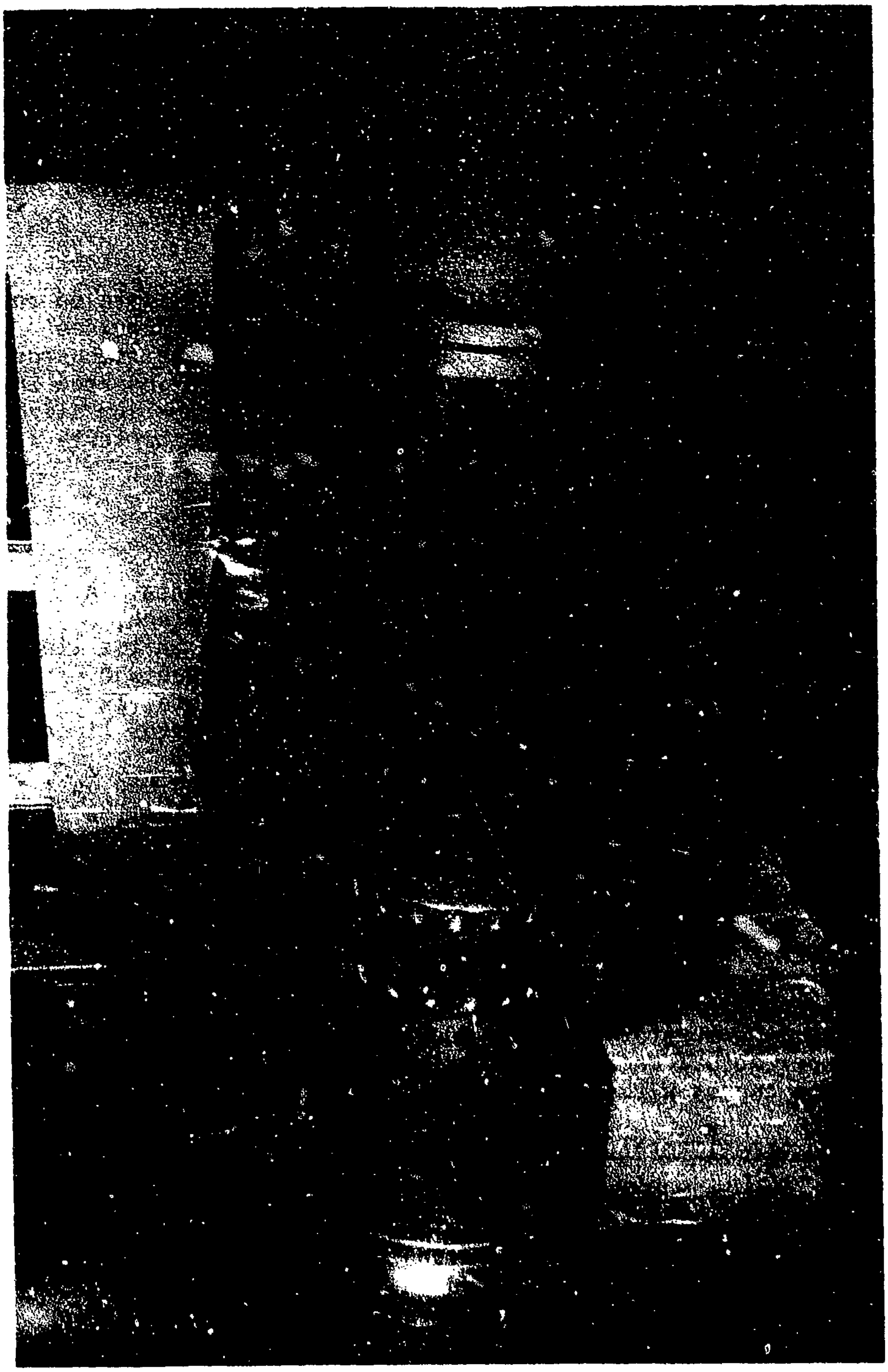

Figure 29. Cold-Flow Experimental System.

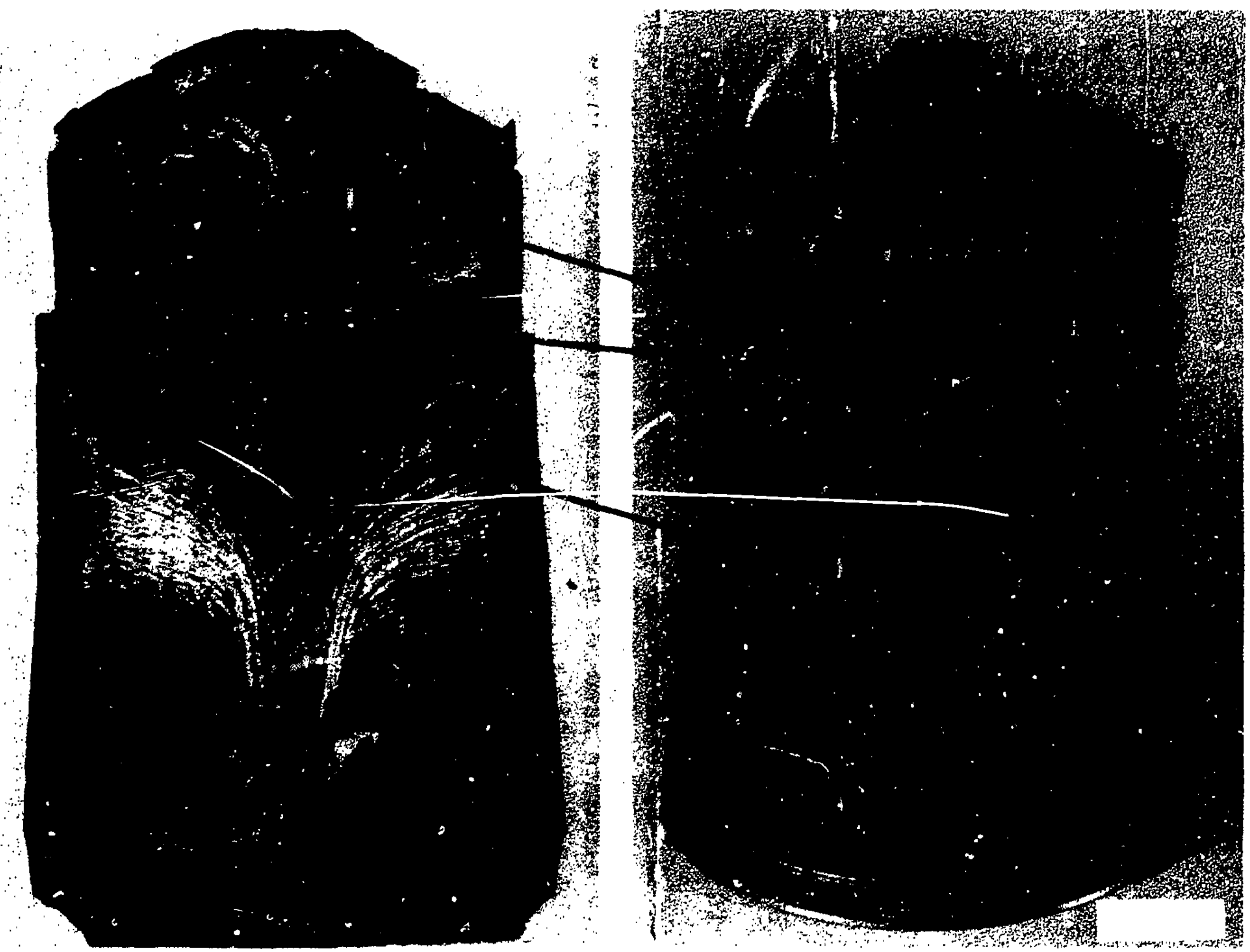

Figure 30. Conventional T63-A-5A Combustor Flow Tracing.

Combustor Inlet Temperature	300°to 970°F
Combustor Inlet Pressure	43 to 92.3 psia
Fuel/Air Ratio	0.0080 to 0.0198
Airflow Rate	1.76 to 3.22 lb/sec

The above combustor operating conditions could be readily simulated under steady-state conditions in the DDA Combustion Research Laboratory. Major elements of the facility used in conducting the experiments were:

- Air supply system.
- Fuel supply system.
- Ignition system.
- Data acquisition and reduction system.
- Emission measurement system.
- T63 combustor test rig.

The systems and experiments were remotely operated from the control room shown in Figure 31 . The above-listed combustion facility elements used in the experiments are described in the following paragraphs.

Air Supply System

The air supply system provided nonvitiated air at the required inlet temperature, pressure, and flow rate to simulate the engine combustor airflow conditions. This system, as shown in Figure 32, includes air filter, air heaters, airflow control, pressure control, flow metering, and exhaust systems. After the air passed through a filter, the airflow was measured with a standard ASME flange tap orifice plate. A throttling valve controlled the airflow rate. An oil-fired Thermal Research air heater and a bank of four electric heaters in parallel, rated at 200 kw each, were used to heat the combustor inlet air temperatures. This heater system is capable of heating the inlet air to 1500°F. However, in this program, the maximum required temperature was 970°F.

The test facility can accommodate two 150-inch-long test sections. Test section connections are made with 10-inch flanges at the inlet and exhaust. In this program, the T63 test rig was installed in one of the 150-inch test sections.

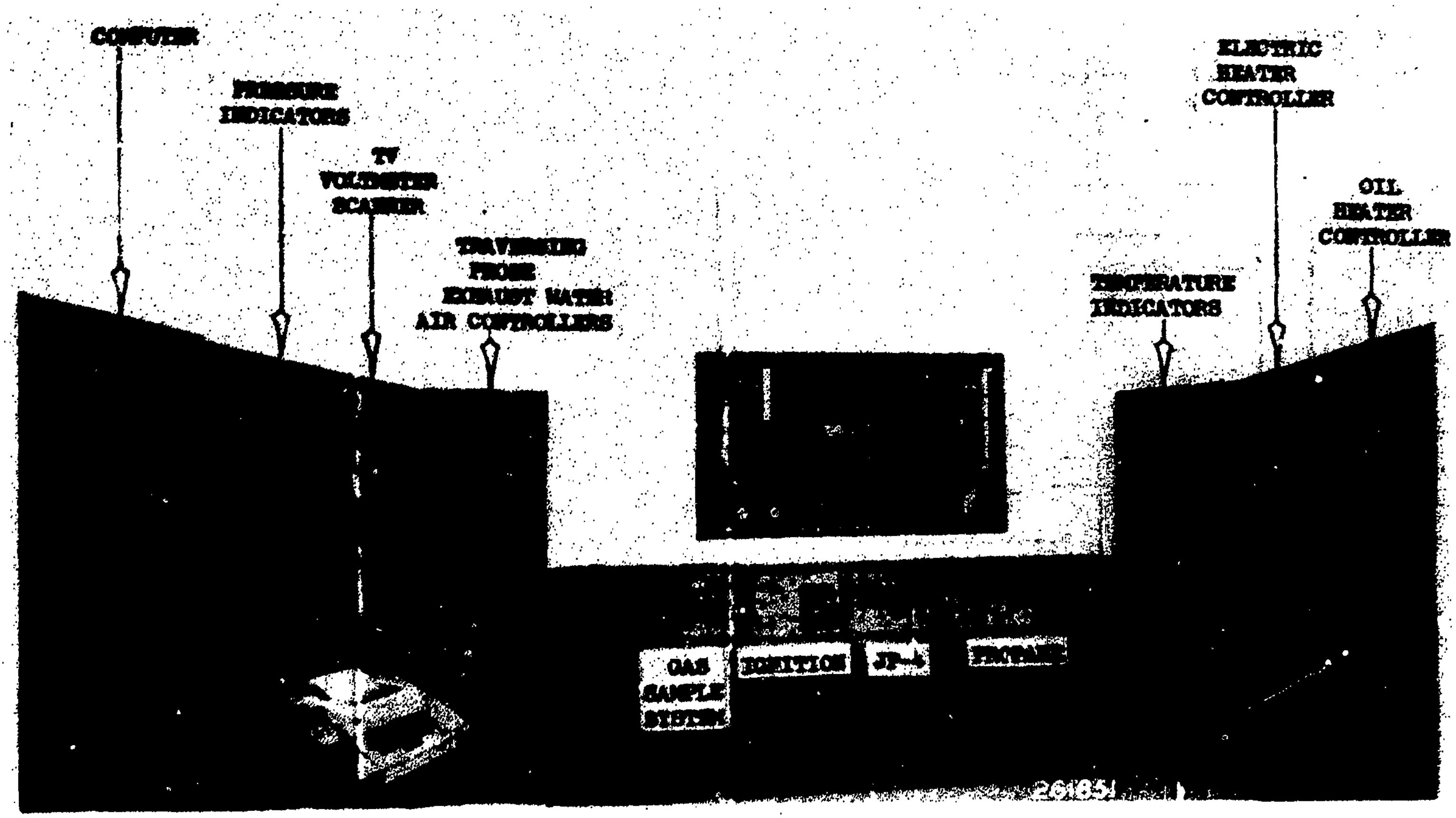

Figure 31. Combustion Research Laboratory Control Room.

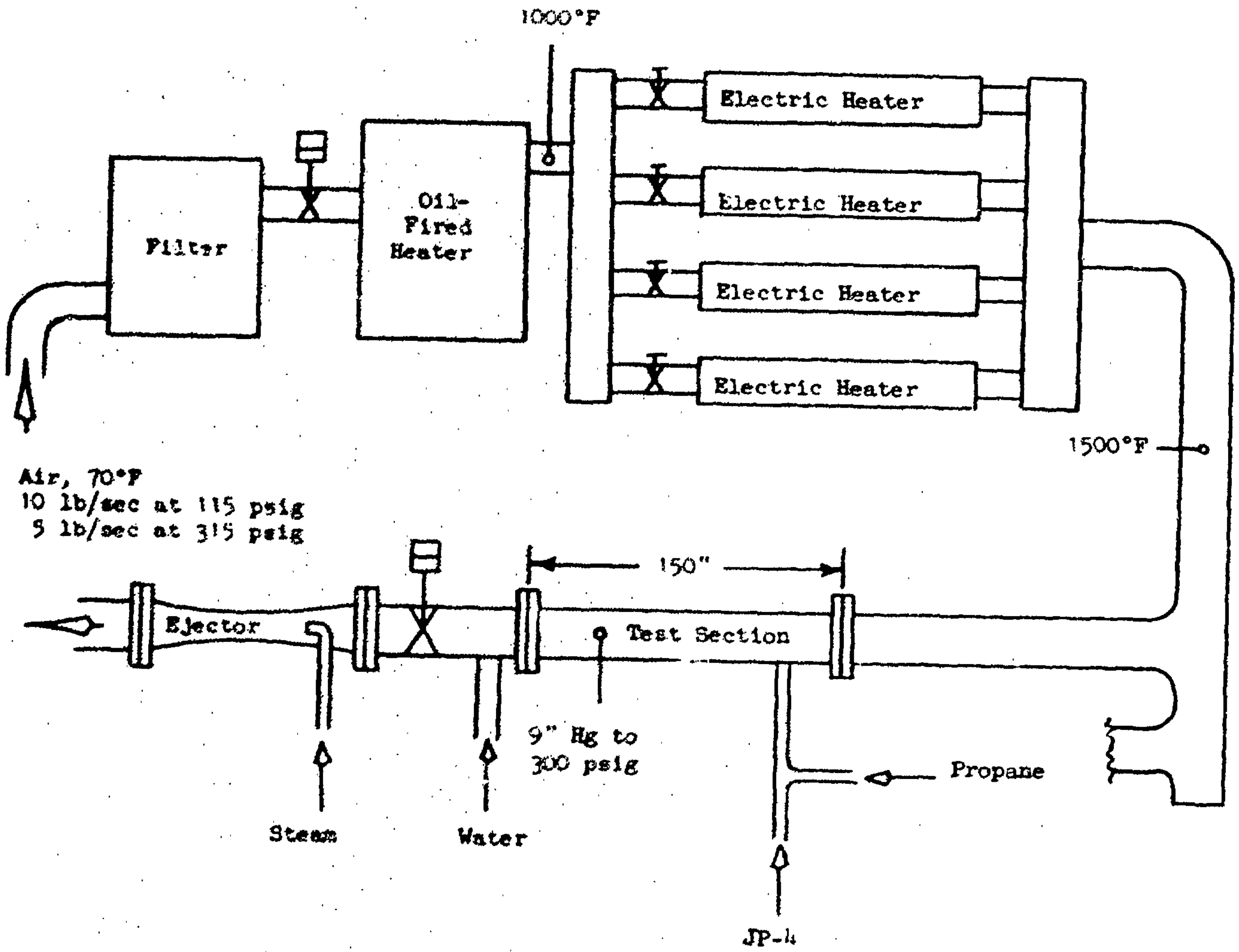

Figure 32. Combustion Research Facility Air Supply Schematic.

The exhaust ducting is equipped with an automatic water spray bar system for cooling the exhaust products to 450°F. The exhaust gas is then either vented to the atmosphere or ducted through a set of steam ejectors. With this system, the test section static pressure can be controlled over a range of pressures from 9 in. Hg absolute up to 300 psia. Altitude simulation was not required in this program, and the pressure was controlled to preselected set point values ranging from 43 psia to 92.3 psia.

Fuel Supply System

All but one of the combustor liners in this program were tested on JP-4 fuel; the remaining liner was tested on gaseous propane fuel. The JP-4 system is capable of supplying fuel at a maximum flow rate of 2450 lb/hr and 2000 psia. These were more than adequate to meet the fuel flow requirements for this program. The JP-4 was stored in an underground tank and transferred by a boost pump to a high-pressure pump which could provide a maximum delivery pressure of 2000 psia. The JP-4 fuel system incorporates a surge tank and feedback system to eliminate any potential pressure pulsations in the fuel flow delivery. JP-4 flow rates were measured with a turbine-type flowmeter which had been calibrated on JP-4 fuel.

The gaseous propane was supplied by a bank of ten cylinders of liquid propane. The delivery pressure was limited to the vapor pressure of propane, which is approximately 100 psig. To assure a constant delivery pressure and flow rate, the bank of propane cylinders was enclosed and convection heated by a forced, heated-air system. The propane flow rate was measured with a turbine-type flowmeter.

Ignition System

The combustor liners which had standard T63-A-5A primary zones were ignited with the conventional T63 spark ignition system. All other combustors were ignited with DDA-designed methane-oxygen torch igniters to ensure ignition in the burner without spending a significant effort on ignition development problems. After a stable flame was obtained, the igniter was turned off before any emission or performance data were taken for the combustor liners. The torch igniters were operated at sufficiently lean fuel/air ratios to assure low igniter flame temperatures to avoid any damage to the combustor liners during ignition.

Data Acquisition and Reduction System

An automatic digital data acquisition and reduction system was used in this program. The system can acquire 200 channels of

input test data in 15 seconds. The principal components of the digital data acquisition system are a cross-bar scanner, digital voltmeter, digital computer, high-speed paper-tape reader, teletype printer, and high-speed paper-tape punch. The digital data acquisition system operates as follows.

- The scanner (as programmed by the computer) steps through the 200 data channels and feeds the signals to the voltmeter. The only restriction is that the input data must be in the form of either voltage or frequency.

- The digital voltmeter reads the signals as received and sends them sequentially to the computer.

- The digital computer reduces the raw data to engineering units, such as pressure and temperature. The computer also operates on the data to calculate the desired flow parameters, such as airflow rate, fuel flow rate, fuel/air ratio, percent pressure drop, and emission indices.

- The calculated data are then printed out by the teletype or can be logged by the high-speed punch.

The cross-bar scanner is a Hewlett-Packard 2911A/B 200-channel unit. The voltmeter is a Hewlett-Packard 2402A integrating digital voltmeter. The computer is a Hewlett-Packard Model 2116B with 16,000 words of memory. The computer is equipped with a high-speed paper-tape reader.

A data acquisition program was written for this program to acquire electrical signals from the various types of instrumentation and to convert those signals to the corresponding engineering units. Once converted, those data were used in the data reduction program to calculate parameters, such as fuel flow, airflow, fuel/air ratio, emission indexes, pressure loss, temperature profile, temperature pattern factor, and other parameters of interest. Some of the data was printed out during the test, such as in Table XVIII. The top group of data in Table XVIII was to achieve the desired "set-point" flow conditions. When the required flow conditions were achieved, the full data acquisition was initiated. Parameters of interest were then immediately "printed out" as shown in the lower half of Table XVIII. A complete listing of data, containing more detailed data as shown in Table XIX, was typed out immediately after the test.

The data reduction calculations for several items shown in Table XIX need to be clarified. These are the calculation of combustion efficiency, chemical fuel/air ratio, and emission

TABLE XVIII. TYPICAL DATA PRINT-OUT DURING TEST

SET FLOW CONDITIONS

WA LB/SEC	BIP PSIA	BIT DEG F	F/A RATIO	BOT DEG F	T-MAX/ T-AVG	FLOW FACTOR	PATTERN FACTOR	DELTA P PERCENT
2.534	63.81	397.	.01311	1308.	1.2182	1.1683	.30175	5.653
2.536	63.85	397.	.01309	1309.	1.2048	1.1630	.29696	5.744
2.543	63.83	398.	.01296	1302.	1.2343	1.1754	.33730	5.697
2.540	63.88	397.	.01304	1303.	1.2263	1.1674	.32540	5.783
2.542	63.84	398.	.01307	1294.	1.2131	1.1658	.30762	5.791
2.504	63.81	397.	.01316	1308.	1.2193	1.1578	.31494	5.760
2.504	63.93	397.	.01316	1316.	1.2243	1.1558	.32147	5.764
2.574	63.81	397.	.01290	1314.	1.2177	1.1807	.31198	5.718
2.553	63.84	397.	.01301	1319.	1.2260	1.1701	.32331	5.783
2.533	63.85	397.	.01311	1308.	1.1953	1.1614	.28858	5.691
2.532	63.90	397.	.01312	1307.	1.2019	1.1601	.29011	5.783
2.553	63.84	397.	.01298	1308.	1.2507	1.1708	.35994	5.743
2.577	63.80	398.	.01289	1303.	1.2216	1.1824	.31893	5.670
2.546	63.92	397.	.01302	1307.	1.2409	1.1656	.34080	5.606
2.529	63.83	397.	.01313	1311.	1.2347	1.1597	.33409	5.673
2.543	63.84	397.	.01305	1303.	1.2199	1.1648	.31424	5.692
2.543	63.89	397.	.01308	1309.	1.2258	1.1659	.32381	5.681
2.540	63.90	397.	.01303	1304.	1.2118	1.1673	.30378	5.644
2.536	63.92	397.	.01305	1305.	1.2281	1.1683	.32797	5.747

```
RDG NO    796 TAKEN AT 1649:58 HOURS
    WA= 2.535  LB/SEC   AVG BIP= 63.78 PSIA    RIG DELTA P= 5.783 %
AVG BIT=  397. DEG F    AVG BOT= 1303. DEG F    T-MAX/T-AVG= 1.2203
F/A RATIO= .01311    FI= 1.1629    THETA=       .31719
HEAT LOAD= .31939E+07 BTU/HR/FT**3/ATM    MAX BOT: # 27 = 1590. DEG F
FUEL FLOW= 119.58 LB/HR (19.385 GPH)


TURN SW 9 ON TO INPUT CHEM DATA.
TURN SW 6 OFF TO ABORT W/O CHEM INPUT


CHEM INPUT
  RANGE, RDG
 O2? 2,18.2
CL  NO? 4,4
CL NOX? 4,4
NO  NO? 3,14.5
NO NOX? 3,11
 CO? 2,41.5
CO2? 2,45
CHX? 2,27
F/A RATIO=  .010090 INCL. O2  EFF=     99.506 %
F/A RATIO=  .010100 EXCL. O2  CALC O2= 18.03 %
O2= 18.20 %  CO2=  2.11 %  CO=  136.72 PPM  CHX=     2.70 PPM
EI'S - LB/1000 LB FUEL      CO=  11.707       CHX=     .318
CL INST: NO=  39.20 PPM   NOX=  39.20 PPM
EI'S -    NO=  4.010          NOX=  4.010
NO INST: NO=  20.40 PPM   NOX=  29.31 PPM (NDIR + NDUV)
EI'S -    NO=  2.303          NOX=  3.396
```

TABLE XIX. TYPICAL DATA PRINT-OUT IMMEDIATELY AFTER TEST

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 65, READING #     798
T63 PRECHAMBER FINAL DESIGN, MOD "A"  RUN STD. CYCLE ON WALL FILM NOZZLE
TEST DATE:  7-12-72                       READING WAS TAKEN AT 1049158 HOURS

CYCLE POINT  5                                          40 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.533 LB/SEC    AVG BURNER INLET TEMP   397. DEG F
AVG BURNER INLET PRES  63.7    PSIA      AVG BURNER OUTLET TEMP 1303. DEG F
AVG BURNER DELTA P       7.98    "HG     PRESSURE LOSS            5.78 %
OVERALL F/A RATIO      .01311  (F/M)     FUEL FLOW RATE         119.58 LB/HR
AIR LOAD FACTOR        1.1639            PATTERN FACTOR         .31719
BOT HOT SPOT: # 27 = 1590.  DEG F        MAX BOT / AVG BOT      1.2285
FUEL INLET TEMPERATURE 133.  DEG F       FUEL INLET PRESSURE      93.6  PSIA
HEAT LOADING PARAMETER  .31938E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1154.  5 1224. 15 1485. 19 1336. 24 1525. 27 1590. 36 1081.
ANNULUS 2  4 1230.  7 1333. 16 1469. 21 1507. 25 1575. 34  992. 37 1020.
ANNULUS 3  8 1169. 14 1408. 17 1396. 22 1592. 26 1558. 35  899. 38 1075.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          63.67   PSIA     TOTAL PRESSURE         63.74   PSIA
STATIC PRESSURE         63.17   PSIA     STATIC PRESSURE        63.38   PSIA
VELOCITY DELTA P         1.01    "HG     VELOCITY DELTA P        .73     "HG
AIR TEMPERATURE         397.   DEG F     AIR TEMPERATURE        397.   DEG F
AIR VELOCITY           151.84 FT/SEC     AIR VELOCITY           128.87 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.146    "HG

AIR FLOW DATA: P-REF= 103.1 PSIA   DELTA P= 3.09 "HG   T-REF= 108. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      441.      HZ     VOLUMETRIC FLOW RATE  18.31 GAL/HR
FUEL PRESSURE AT F/M  163.6    PSIA      FUEL TEMP AT F/M         88.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    60.92 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             62.66 PSIA (XDUCER = 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.43  "HG (XDUCER = 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2   2.107 %     O2  18.209 %     CO   156.7 PPM     CHX      2.7 PPM
 NO    20.4 PPM  NO2       8.9 PPM  NOX    29.3 PPM (NO(NDIR) + NO2(NDUV))
 NO    30.2 PPM  NO2        .0 PPM  NOX    30.2 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.71                  CHX=     .32
                 CHEMILUMINESCENCE NOX=   4.01,   NDIR + NDUV NOX=    3.89

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .010890
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.5883 %
   CHECK ON F/A RATIO- F/A = .010100 W/O O2, CALCULATED O2 = 18.032 %

SMOKE INDEX:  6.20
SALTZMAN NOX = 31.5              PPM      E.I. = 3.87
-------------------------------------------------------------------------
REMARKS:
```

indexes. The combustion efficiency was calculated from the exhaust gas analysis data by the following equation:[31]

$$\eta_b = 1 - \frac{fr_{CO}(-121,745) + fr_{HC}\ (-879,347) - fr_{NO}(38,880) - fr_{NO_2}(14,564)}{(fr_{CO} + fr_{CO_2} + 3\ fr_{HC})\ \ (A)} \tag{7}$$

The chemical fuel/air weight ratio was calculated as (1) a check on the fuel and airflow rate measurements and (2) a check on the emission gas sampling method to ensure that a valid sample is obtained from the exhaust. The chemical fuel/air weight ratio in hydrocarbon fuel-air reactions was calculated from exhaust gas analysis by the following equation:

$$F/A_{wgt} = \frac{(fr_{CO_2} + fr_{CO} + 3\ fr_{HC})\ \ (B)}{fr_{O_2} + fr_{CO_2} + fr_{NO_2} + 0.5\left[fr_{CO} + fr_{NO} + (C)(fr_{CO_2} + fr_{CO} - 3\ fr_{HC})\right]} \tag{8}$$

In the above equations, fr_{XX} is the volume fraction of the component as reported by gas analysis. The subscript HC is unburned hydrocarbons, reported as C_3H_8. The values of the constants (A), (B), and (C) are listed in Table XX for the JP-4 fuel and propane fuel used in this program.

The emission indexes (EI) for carbon monoxide, hydrocarbons, and oxides of nitrogen shown in Table XIX were calculated by the following equations.

$$EI_{CO} = \frac{28.011\ C_{CO}\ (1 + F/A)}{28,970\ F/A} \tag{9}$$

$$EI_{H/C} = \frac{44.097\ C_{H/C}\ (1 + F/A)}{28,970\ F/A} \tag{10}$$

$$EI_{NO_x} = \frac{46.008\ C_{NO_x}\ (1 + F/A)}{28,970} \tag{11}$$

The volumetric concentration (C) in parts per million of NO_x used in the above equation was the sum of NO and NO_2 as measured by the NDIR and NDUV instruments.

TABLE XX. FUEL CONSTANTS FOR CALCULATION OF COMBUSTION EFFICIENCY AND FUEL/AIR RATIO

	Fuel Constants		
Fuel	A	B	C
JP-4	263,070	0.10154	0.9910
Propane	292,936	0.10655	1.3334

Emission Measurement System

Most of the emission measurements were made on-line using the following instruments.

Sample	Instrument
Carbon monoxide (CO)	Beckman Model 315BL NDIR (0-100 ppm to 0-5000 ppm)
Carbon dioxide (CO_2)	Beckman Model 315B NDIR (0-5% and 0-25%)
Oxygen (O_2)	Beckman Model 715 Electrochemical Transducer (0-5% and 0-25%)
Nitric oxide (NO)	Beckman Model 315AL NDIR (0-150 ppm to 0-1500 ppm)
Nitrogen dioxide (NO_2)	Beckman Model 255 (long path) NDUV (0-100 ppm to 0-2500 ppm)
Total nitrogen oxides (NO_x)	Air Monitoring Inc. Chemiluminescent Analyzer with NO_2 converter (0-1 ppm to 0-1000 ppm)
Unburned hydrocarbons (H/C)	Beckman Model 402 THC Analyzer (FID) (0-2 ppm C_3 to 0-10,000 ppm C_3)
Smoke	SAE-ARP 1179 system

The on-line emission analysis system is unique in design and instrumentation. The system consists of two units: an analyzer console and a control console. To maintain minimum sample transport time, the analyzer console is located in the test cell. The analyzer console, shown schematically in Figure 33, contains the actual gas analysis instrumentation and is electronically connected to the amplifier/readout units in the control console located in the control room (Figure 31). In addition to the readout units, the control console provides flow control to the analyzer and the sample bypass.

The gas sample line from the test section to the analyzer console was Teflon-lined, stainless-steel tubing heated to 375°F. Suitable filters, condensers, and driers were provided in the analyzer console to assure accurate measurements.

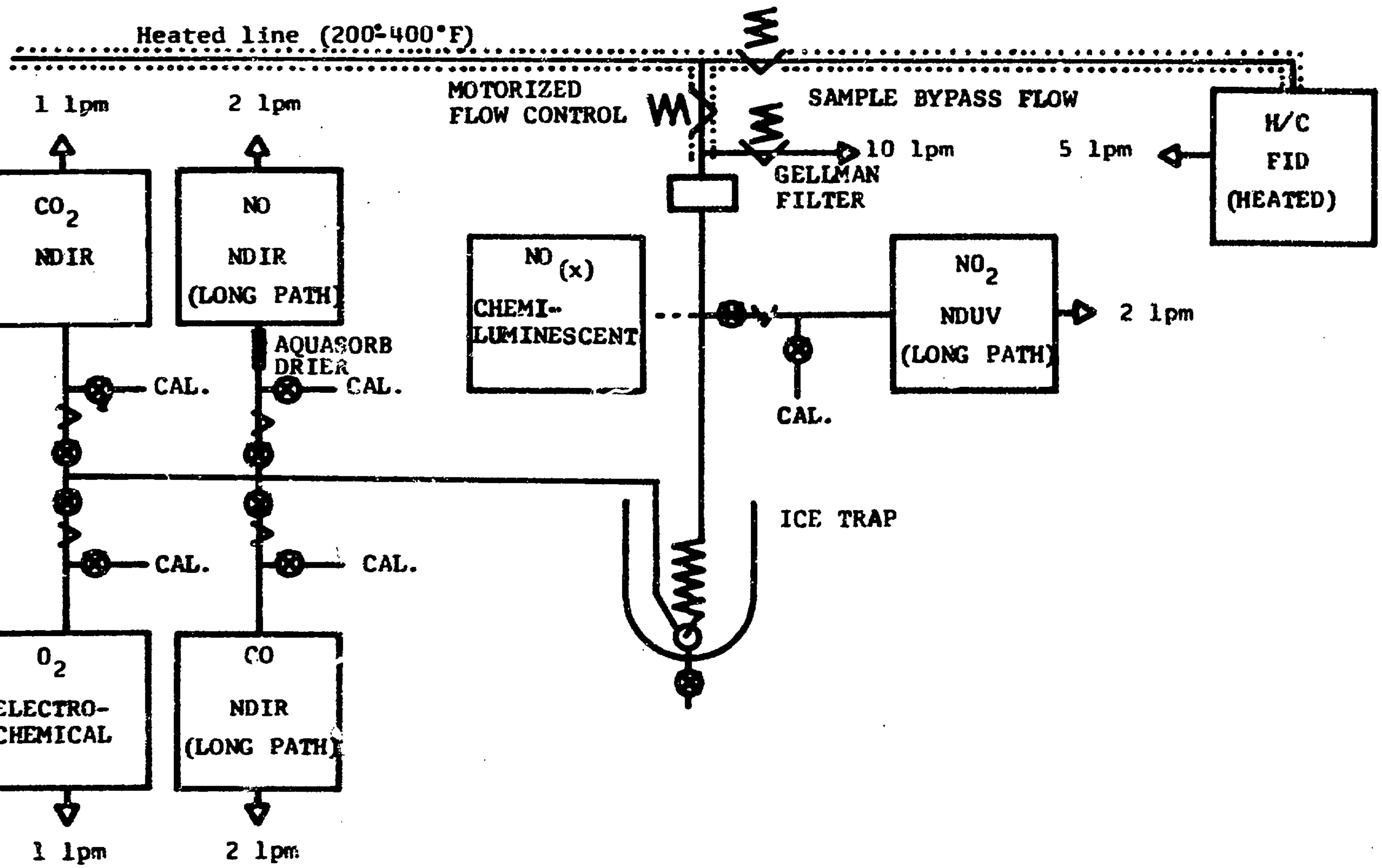

Figure 33. On-Line Emission Analysis System Schematic.

The on-line instruments were calibrated through the use of calibration gases. Gases were available to provide normally five calibration points per analyzer range. The actual gas concentrations were determined by the vendor and checked by the DDA Physical Chemistry Research Section.

The major problem encountered in the operation of the on-line instruments occurred with the AMI, Chemiluminescent NO_x instrument. Its operation was not reliable, and during many of the tests it was not used because it was being modified or repaired.

In addition to the on-line emission instruments, grab samples were obtained and analyzed by the modified Saltzman technique to determine NO_x. This wet-chemical procedure was developed originally as a colorimetric microdetermination of the concentrations of NO_2 in the atmosphere. It has been adapted to exhaust gas measurements by allowing the complete oxidation of NO to NO_2 prior to analysis. The standard Saltzman reagent was used, and the results were analyzed with a Beckman Model S spectrophotometer.

Three systems were thus used in this program to measure the NO_x emissions. Based upon experience in this program, it was concluded that above 20 ppm of NO_x, the NDIR plus NDUV instruments gave the most accurate data; below 20 ppm, the modified Saltzman technique is the most reliable, accurate method.

T63 Combustor Test Rig

All the combustors in this program were tested in a T63 combustor test rig as shown in Figure 34, which exactly simulated the flow path and dimensions of the T63-A-5A engine. The inlet air feed arms, outer combustor case, and turbine inlet section pieces were actual T63-A-5A engine components.

In the early experiments in this program, the emissions were measured in two axial locations. The first location was at the turbine inlet section as shown in Figure 35. Thirty-two ports were provided as shown in Figure 35, to sample the combustor exhaust gas. These consisted of eight probes installed at equally spaced, circumferential locations, and each of the eight probes had four ports located radially to provide equal area sampling. The thirty-two ports all fed into a common manifold external to the rig. From the common manifold, the gases passed through the heated gas sample line to the analyzer console. In addition to the gas sample ports, the turbine inlet instrumentation plane, as shown in Figure 35, contained two combustor outlet pressure probes, twenty-one C-A thermocouples, and four engine thermocouples.

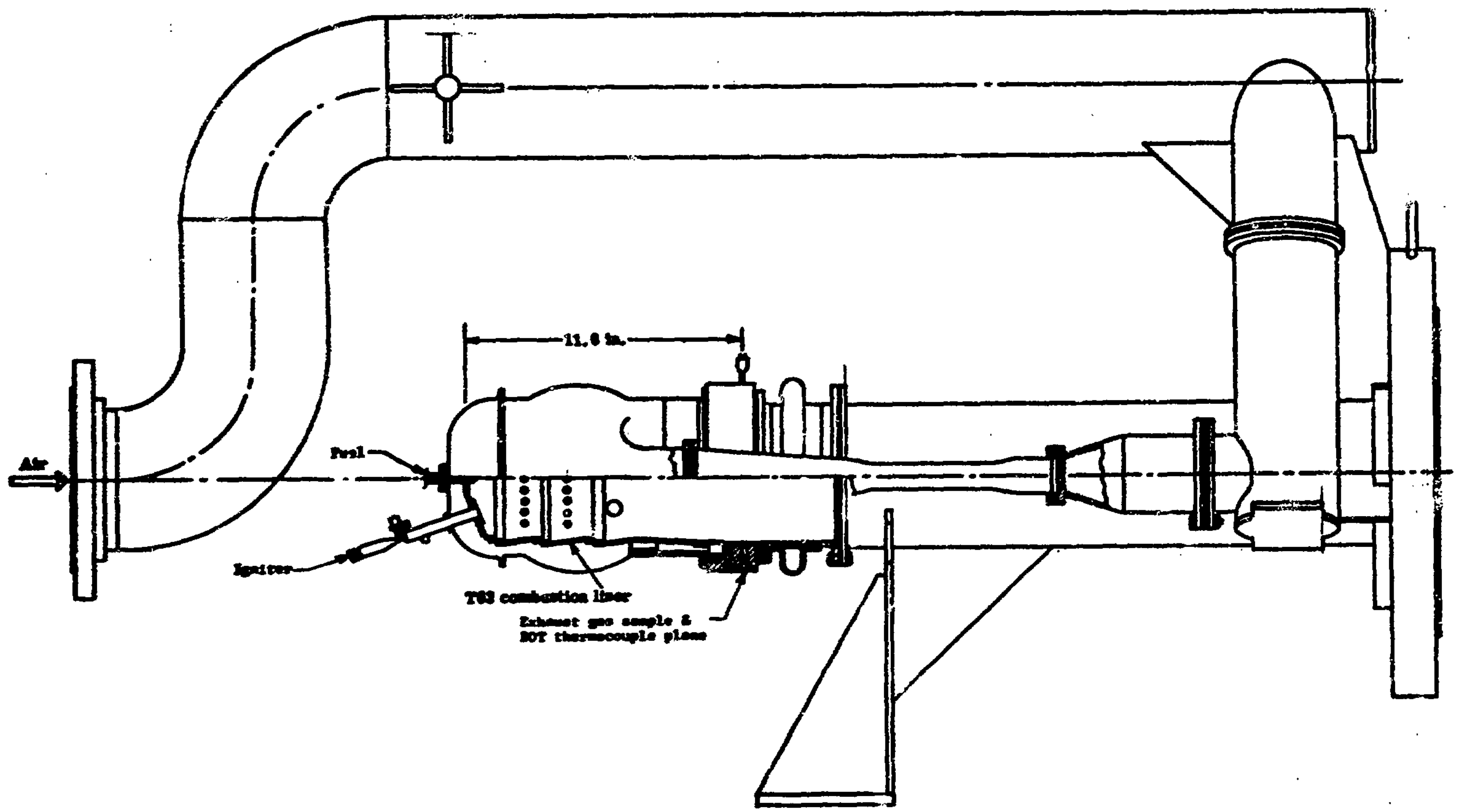

Figure 34. Experimental Installation of T63 Combustion System.

Figure 35. Combustor Exhaust Instrumentation at Turbine Inlet Section.

In addition to the instrumentation plane at the turbine inlet, a gas sample plane, as shown in Figure 36, was located 8 inches downstream from it. This downstream instrumentation plane contained four probes with four ports in each probe. The probes were equally spaced on the circumference, and the ports were located on the radius to provide equal area sampling. In addition to the four probes, an isokinetic probe, as shown in Figure 36, was installed in the center. Test results obtained in this program showed that the emissions measured in the turbine inlet plane were essentially the same as those measured at the downstream location. Therefore, the downstream gas was not sampled in subsequent experiments. The fact that additional carbon monoxide and hydrocarbon reactions did not occur with the additional residence time was due to the relatively low combustor outlet temperatures of less than 1900°F.

During the program, the turbine inlet centerbody was modified, as shown in Figure 37, to install a quartz window. A periscope was then installed as shown in the figure so that the flame could be watched during the tests. As shown in Figure 38, the viewing path was directly upstream into the combustor. The centerbody installation was designed for rapid, easy replacement of the quartz window. Another design feature was that the window was swept with air to avoid deposit buildup during the experiments. This air was turned off prior to making any emission measurements. An interesting observation during the program was that even without any air on the window, it remained free of deposition and erosion when smoke-free, low-emission combustors were tested. On conventional and other high-emission combustors, the quartz window was pitted (eroded) and dirty after the experiments and required frequent replacement. Therefore, it is speculated that a low-emission combustor will provide longer-life turbines.

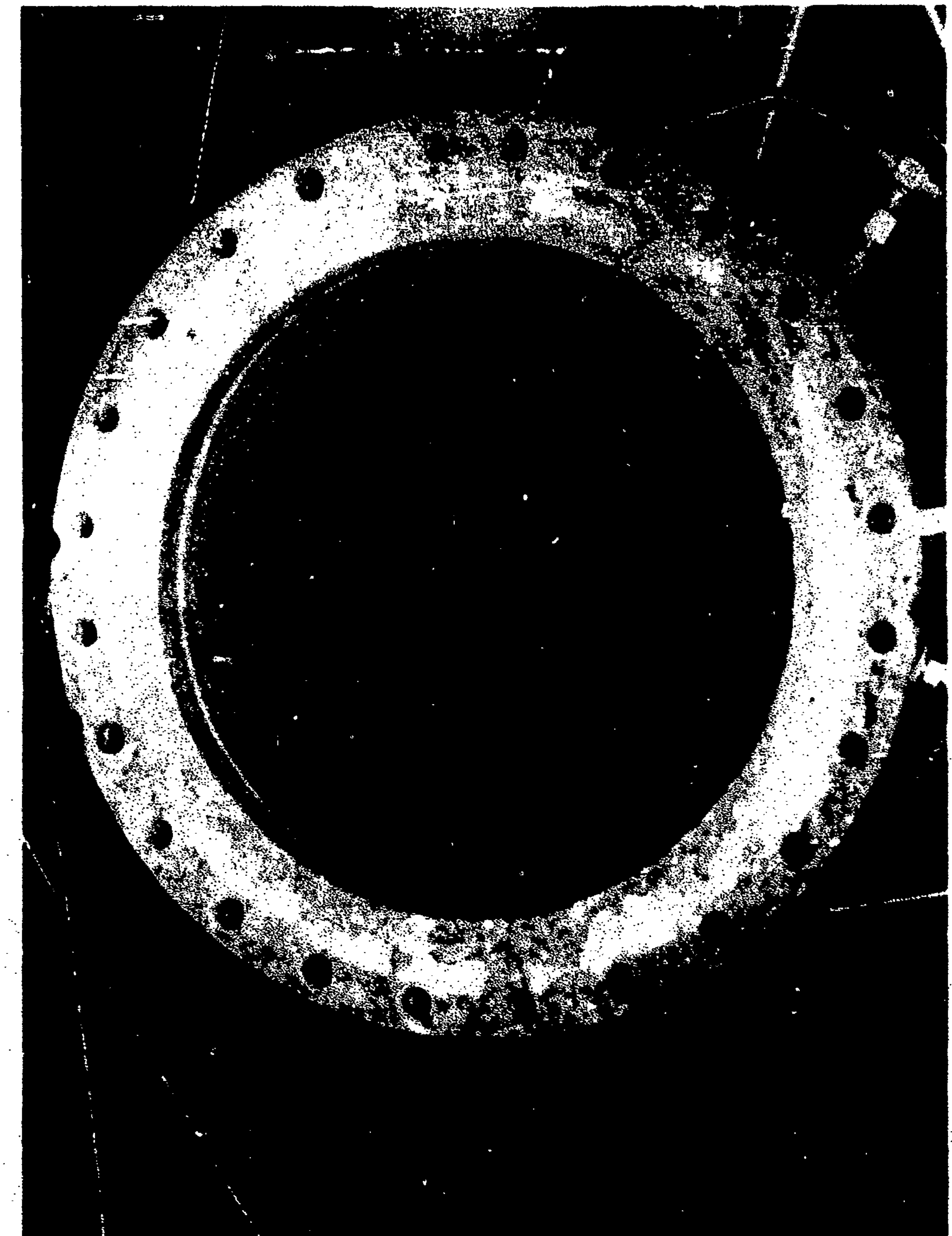

Figure 36. Combustor Exhaust Instrumentation 8 Inches Downstream of Turbine Inlet Section Instrumentation.

Figure 37. Periscope Assembly and Modified Turbine Inlet Centerbody.

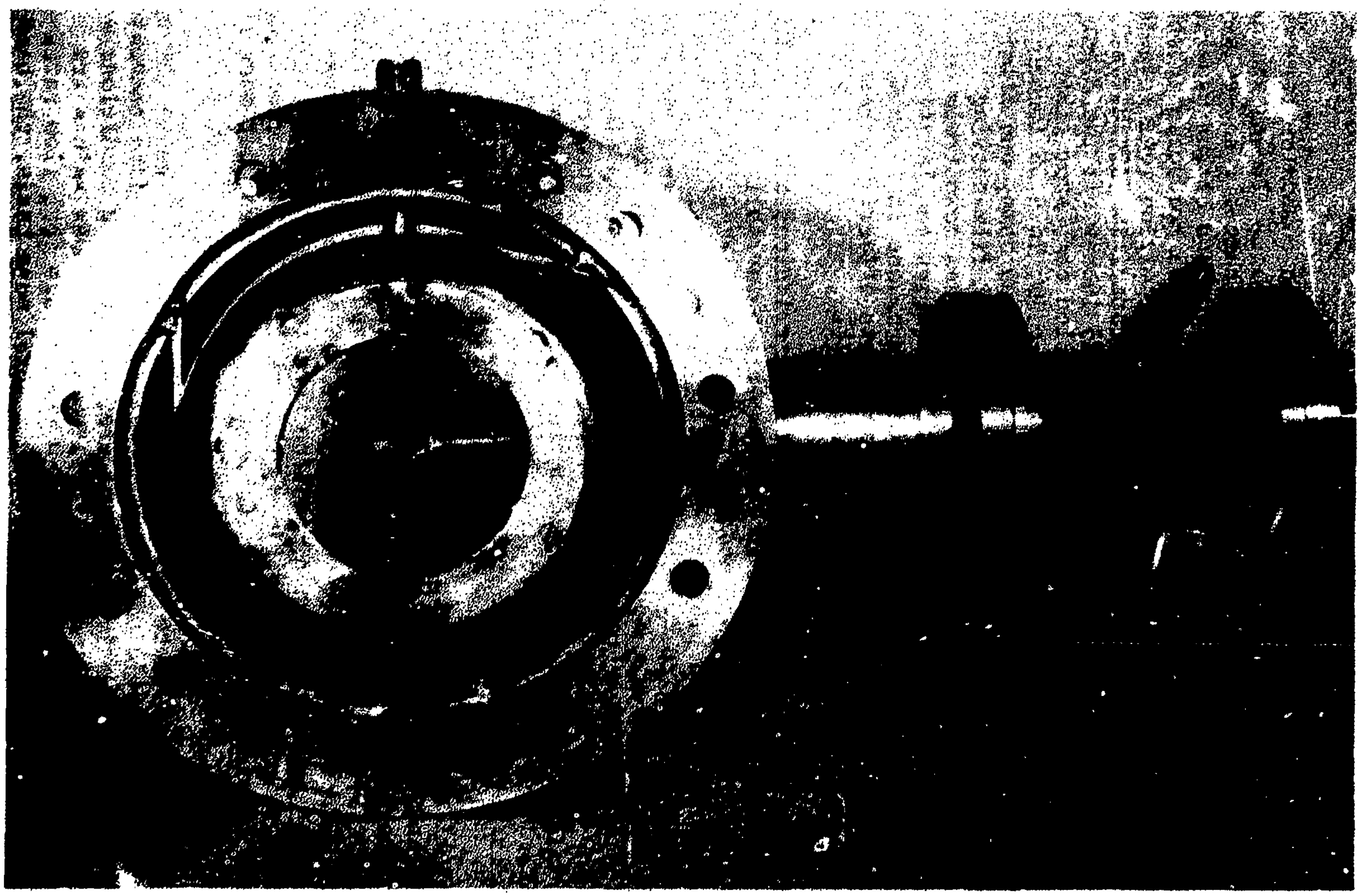

Figure 38. Periscope Viewing Path Through Quartz Window.

Baseline Combustor

The nonregenerative T63-A-5A gas turbine engine combustor liner was the baseline combustor liner used on this contract. It was against the emissions measured on this combustor liner that all low-emission combustor liners were compared. A photograph of the baseline T63 liner is shown in Figure 39. The standard T63 production combustor system consisted of a dual-orifice pressure atomizing fuel injector located in the center of the liner dome, a capacitive discharge spark igniter located in the liner dome 1.25 inches off the liner axial centerline, and a "can" type film-cooled combustor liner. The T63-A-5A combustor liner, shown in Figure 39, is 9.56 inches long overall. The liner has film cooling in the dome, one film-cooling annulus at the dome exit, and one final film-cooling annulus of identical geometry located 1.83 inches downstream of the first film-cooling annulus. Liner hole sizes and locations are summarized in Table XXI. Using the dimensions in Table XXI, the resulting liner airflow splits based upon effective areas through the liner are tabulated in Table XXII.

The similarity between T63 engine measured emissions and test rig measured emissions is shown in the comparison curves in Figures 40 through 42 for CO, C_xH_y, and NO_x. For particulates the mass generation rates were plotted instead of smoke index, see Figure 43. In general, the engine hydrocarbons and particulates were somewhat higher than the levels measured on the combustion rig, but carbon monoxide and nitrogen oxides were slightly lower. Comparing the emission index values computed from these emission concentrations, Table XXIII, the total emissions from engine and rig measurements were nearly identical: 32,933 lb/1000 lb fuel for the engine and 32.945 lb/1000 lb fuel for the rig test.

The baseline T63-A-5A combustor liner was tested at T63 regenerative engine conditions as well as at the conventional or nonregenerative conditions. The emissions measured during these tests are presented in Table XXIV along with pressure loss and temperature profile results. These data, plotted in Figures 44 through 47, show that, operating at the higher reaction zone temperatures of the regenerative combustor conditions, the baseline T63 combustor liner produced considerably less CO, C_xH_y, and particulates but more NO_x emissions.

Using the emission data from Table XXIV and Figures 44 through 47, the LOH duty cycle emissions indexes for the baseline combustor liner at nonregenerative and regenerative operating conditions were computed. The constituent and total emission index values are summarized in Table XXV along with the average fuel flow rates required for the LOH duty cycle. On a total mass basis, the baseline combustor produced an average of 4.63 lb/hr of total emissions at nonregenerative combustor operating conditions, but only 2.21

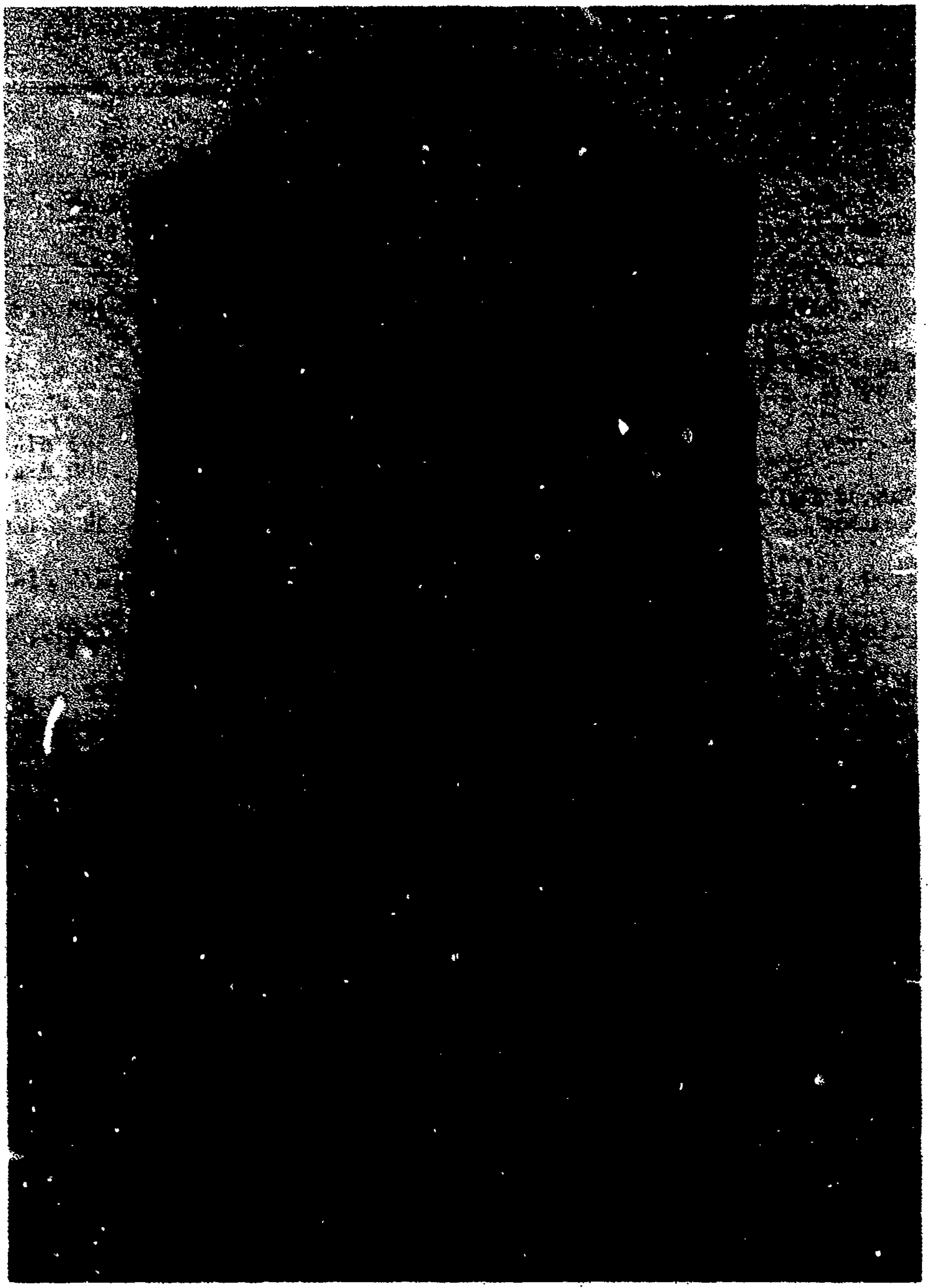

Figure 39. Baseline T63-A-5A Combustor Liner.

TABLE XXI. T63-A-5A LINER - DESIGN SUMMARY					
Item	Axial Location From Dome Exit (in.)	Liner Dia. (in.)	Type Opening	Number	Size (in.)
Dome Cooling	-	1.74-4.66	Holes	54	.203 dia.
First Cooling Annulus	.0	5.31	Slots	22	.39 x .10
Primary	1.40	5.31	Holes	6 6	.562 dia. .500 dia.
Second Cooling Annulus	1.83	5.31	Slots	22	.39 x .10
Trim	2.89	5.52	Holes	14	.375 dia.
Dilution	4.14	5.70	Holes	2	1.250 dia.
Exit	8.19	6.21	-	-	-

TABLE XXII. BASELINE T63-A-5A LINER - AIRFLOW AREA SLITS	
Inlet Air Location	Airflow Area Split (%)
Dome Holes	11.8
First Cooling Step	11.2
Primary Holes	26.4
Second Cooling Step	11.2
Trim Holes	15.2
Dilution Holes	24.2
	100.0

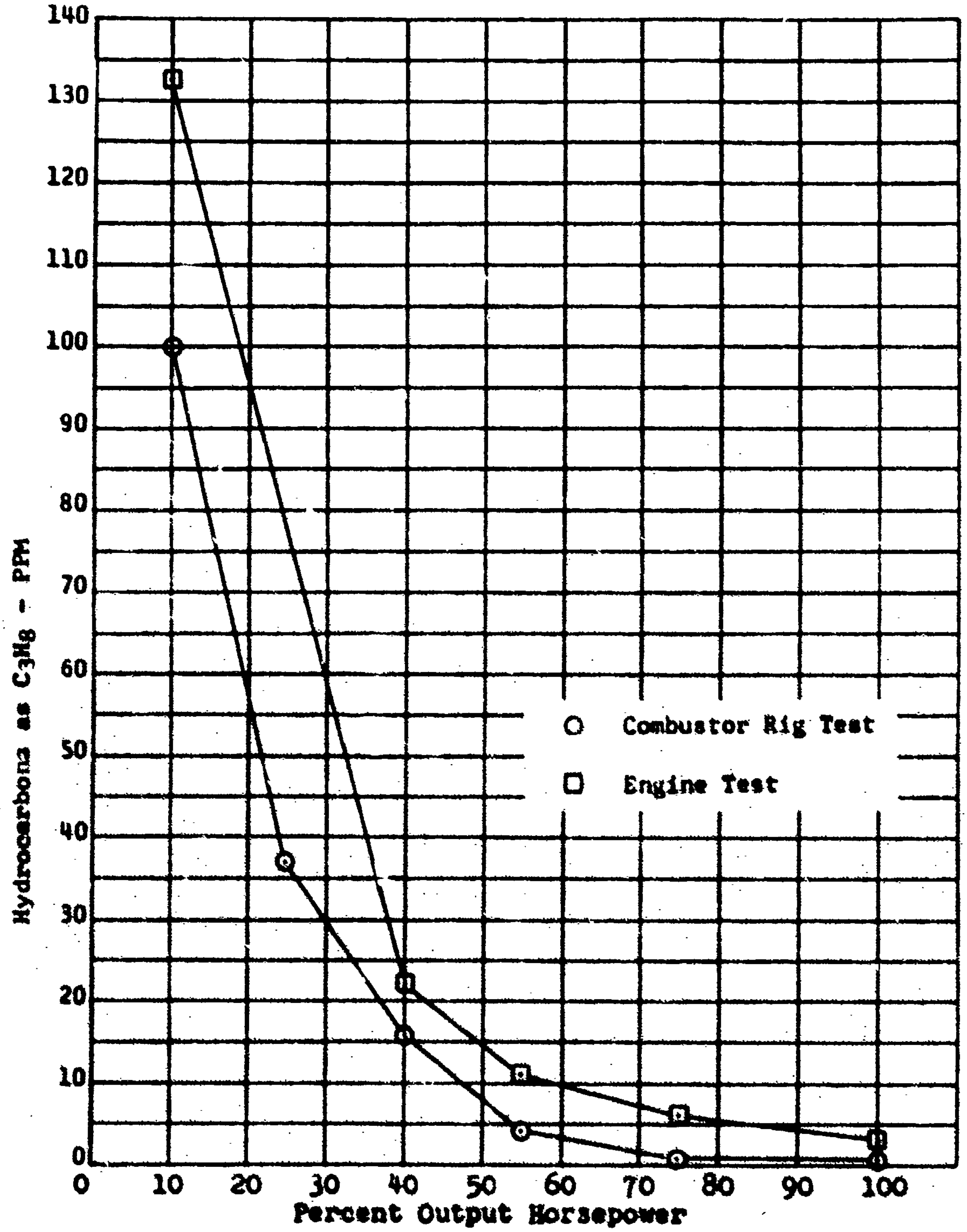

Figure 40. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data.

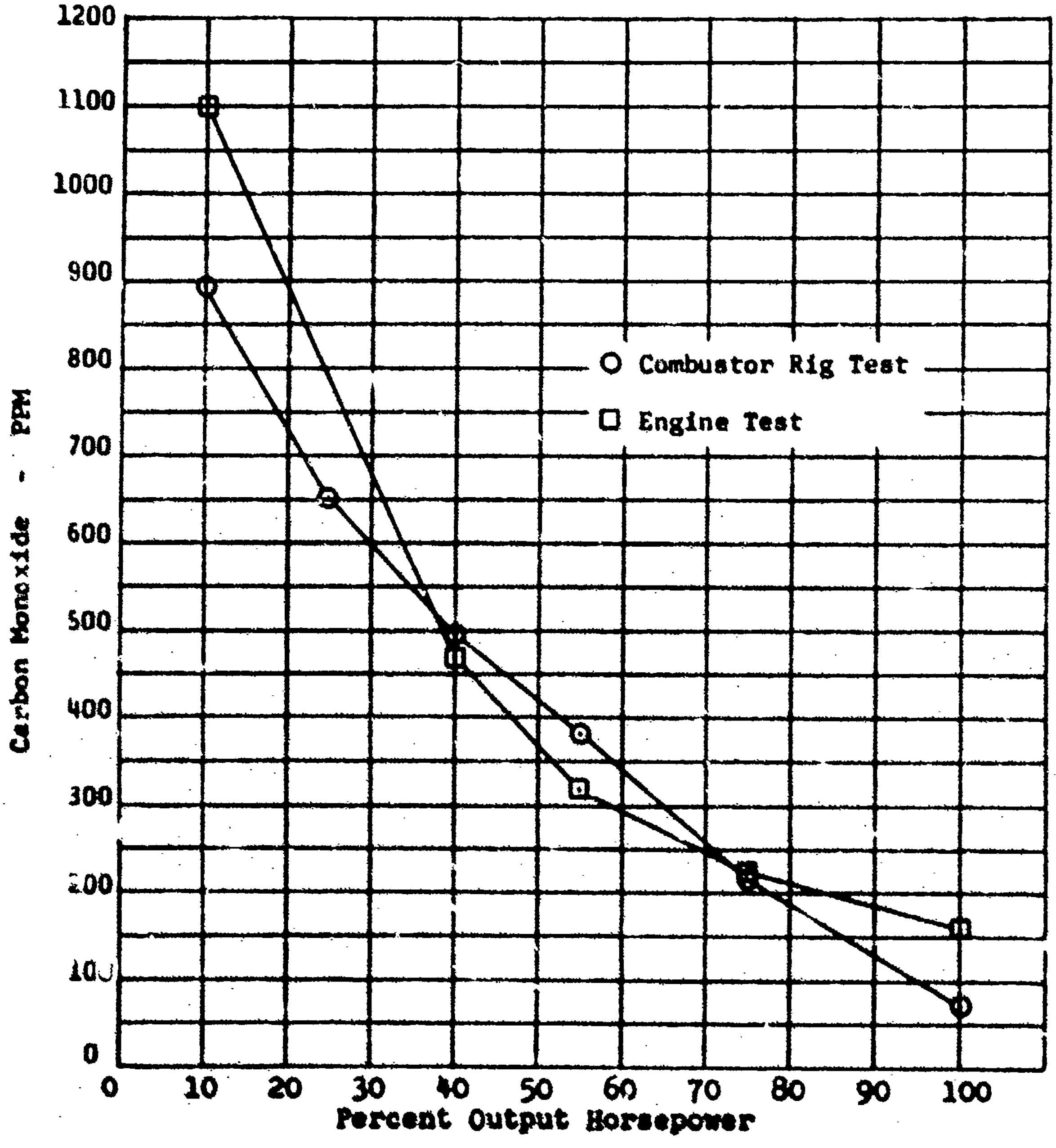

Figure 41. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data.

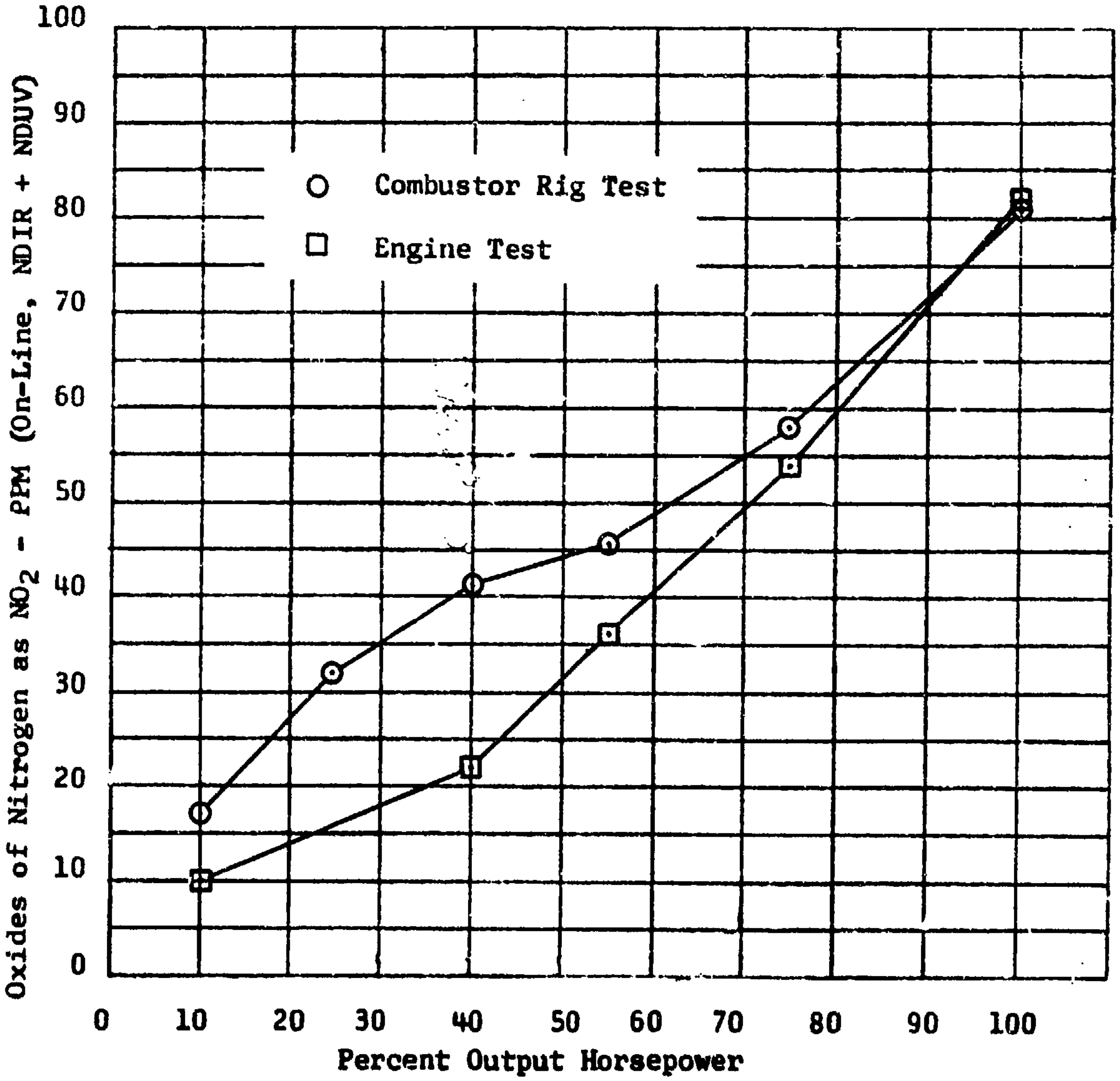

Figure 42. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data.

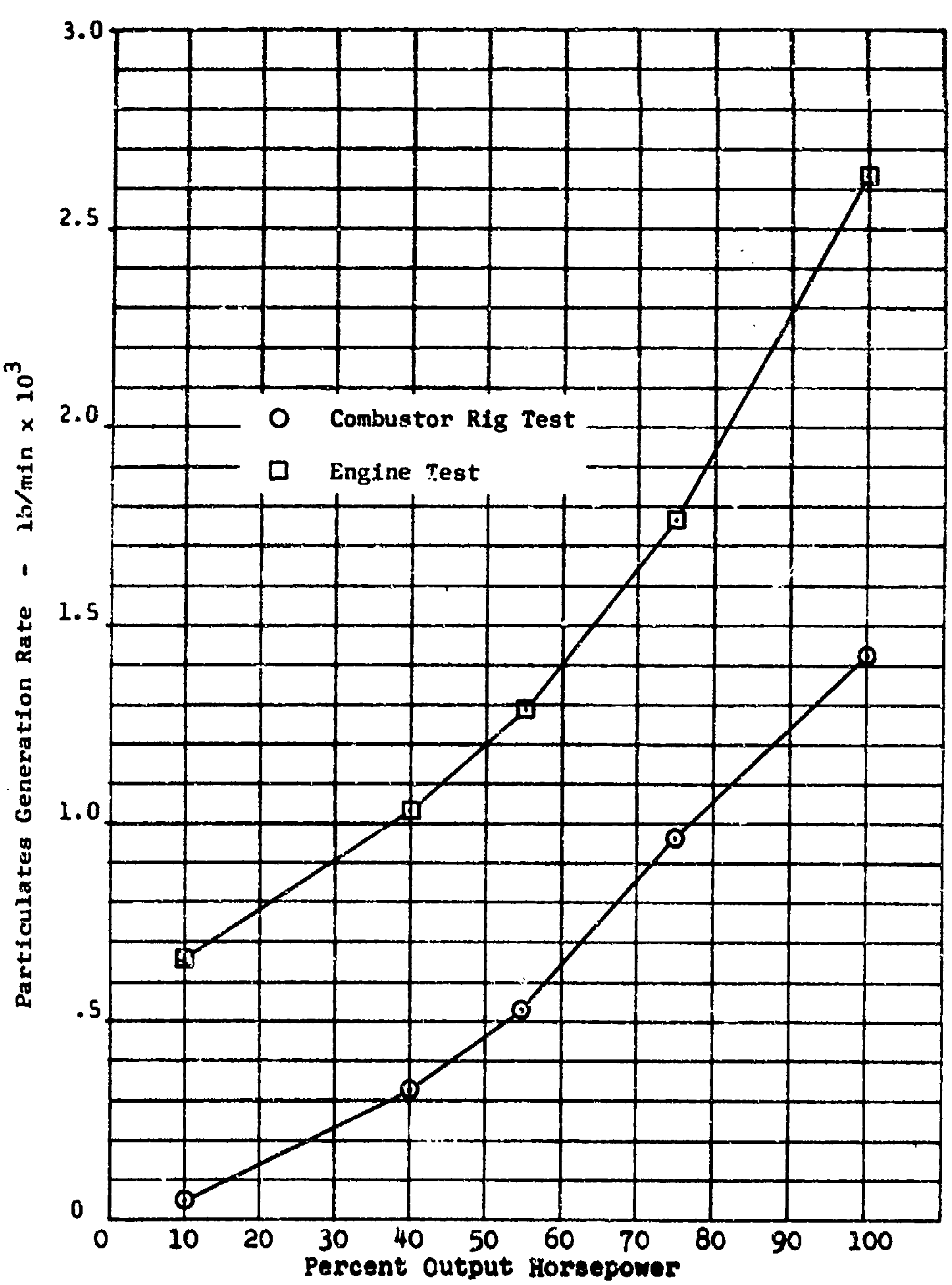

Figure 43. Nonregenerative T63-A-5A Combustor Mass Particulates Generation Rate Emission Data.

TABLE XXIII. COMPARISON OF T63-A-5A ENGINE AND COMBUSTOR RIG EMISSIONS FOR THE LOH DUTY CYCLE

	T63 Combustor Rig		T63 Engine	
Emission	lb/1000 lb Fuel	%	lb/1000 lb fuel	%
C_xH_y	1.544	100	2.467	160
CO	26.094	100	25.784	99
NO_x	5.068	100	4.118	81
Particulates	.239	100	.564	236
Total	32.945		32.933	

TABLE XXIV. COMPARISON OF T63 BASELINE LINER EMISSIONS/COMBUSTOR PERFORMANCE AT (1) NONREGENERATIVE AND (2) REGENERATIVE COMBUSTOR OPERATING CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner-Nonregenerative Conditions						
A. Emissions						
CO, PPM	892.7	651.5	495.5	382.9	214.1	74.7
H/C, PPM	100.0	37.0	15.8	4.1	0.7	0.6
NO_x, PPM (On-Line, NDIR & NDUV)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, PPM (On-Line, CL)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, PPM (Saltzman)	18.5	27.8	37.1	45.8	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Conventional Liner-Regenerative Conditions						
A. Emissions						
CO, PPM	346.2	242.5	196.8	142.9	85.8	38.0
H/C, PPM	8.8	2.6	1.6	1.5	3.3	1.5
NO_x, PPM (On-Line, NDIR & NDUV)	-	-	-	-	-	-
NO_x, PPM (On-Line, CL)	27.0	33.6	39.4	53.8	75.8	102.9
NO_x, PPM (Saltzman)	-	-	-	-	-	-
Smoke Number	2.00	.83	1.35	2.05	4.50	2.50
B. Pressure Loss (%)	6.50	6.52	7.00	6.85	6.27	6.64
C. Temp. Profile (T_{max}/T_{avg})	1.076	1.085	1.079	1.063	1.065	1.050

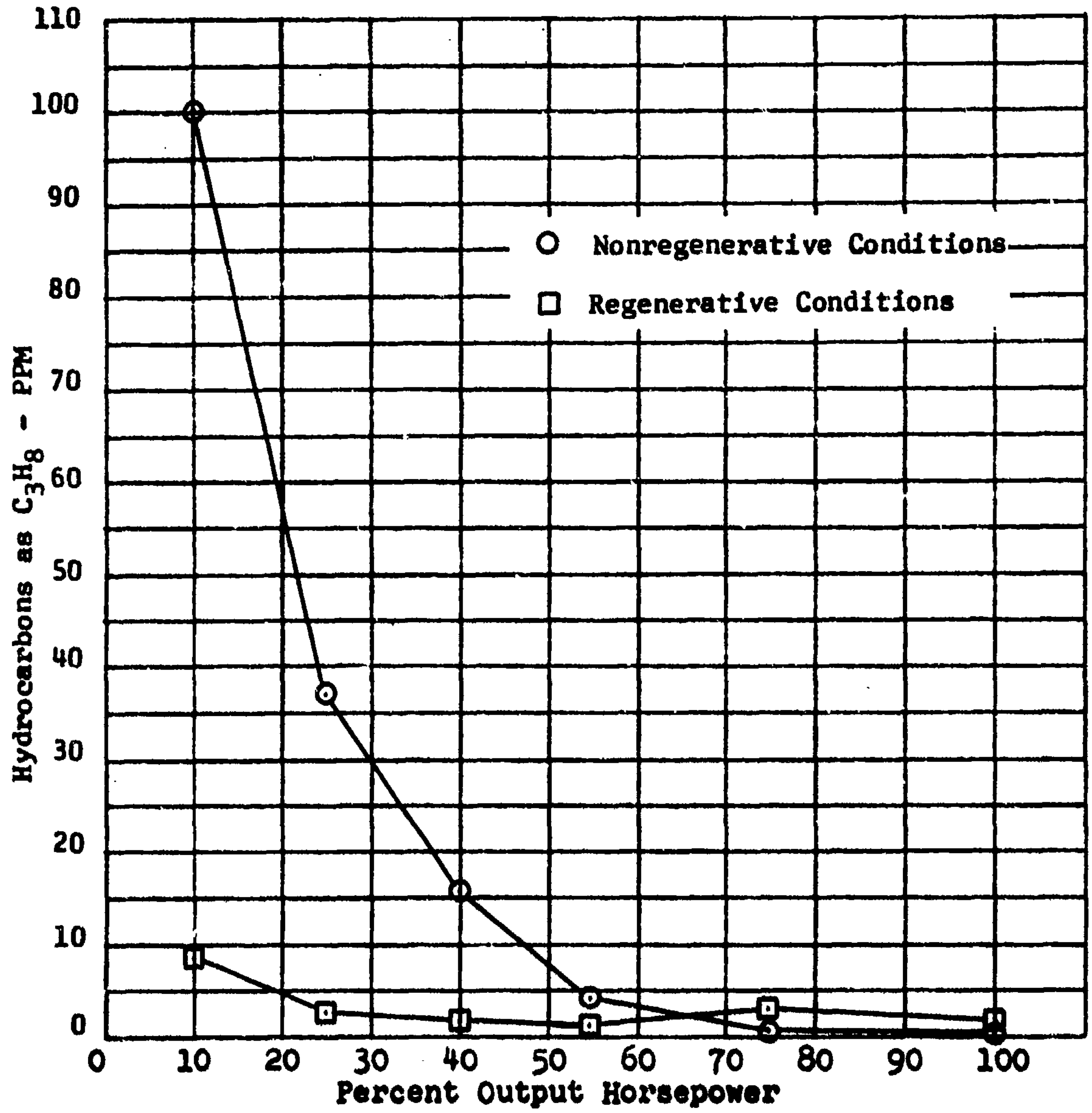

Figure 44. Conventional T63-A-5A Baseline Combustor Hydrocarbon Emission Test Rig Data.

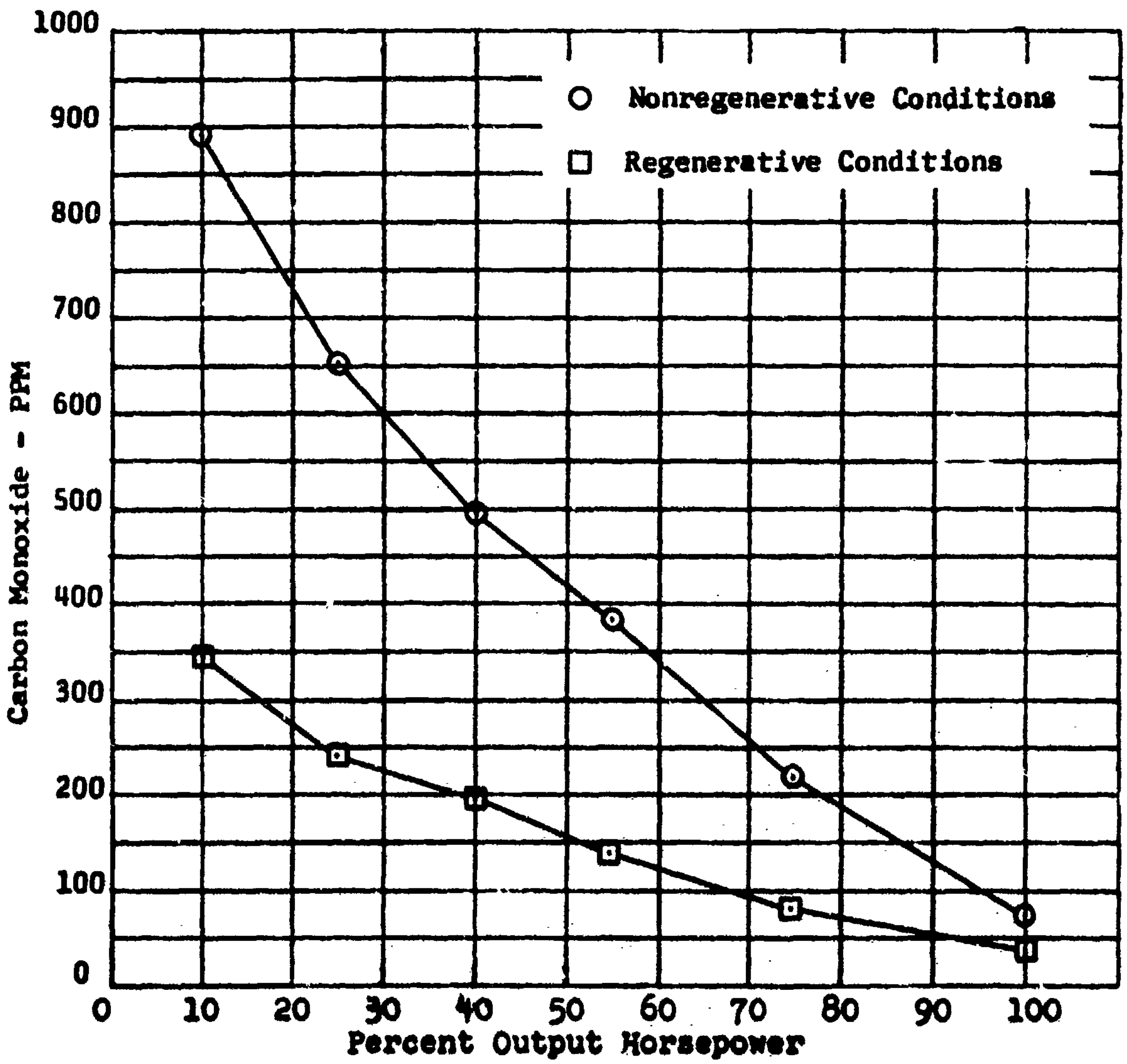

Figure 45. Conventional T63-A-5A Baseline Combustor Carbon Monoxide Emission Test Rig Data.

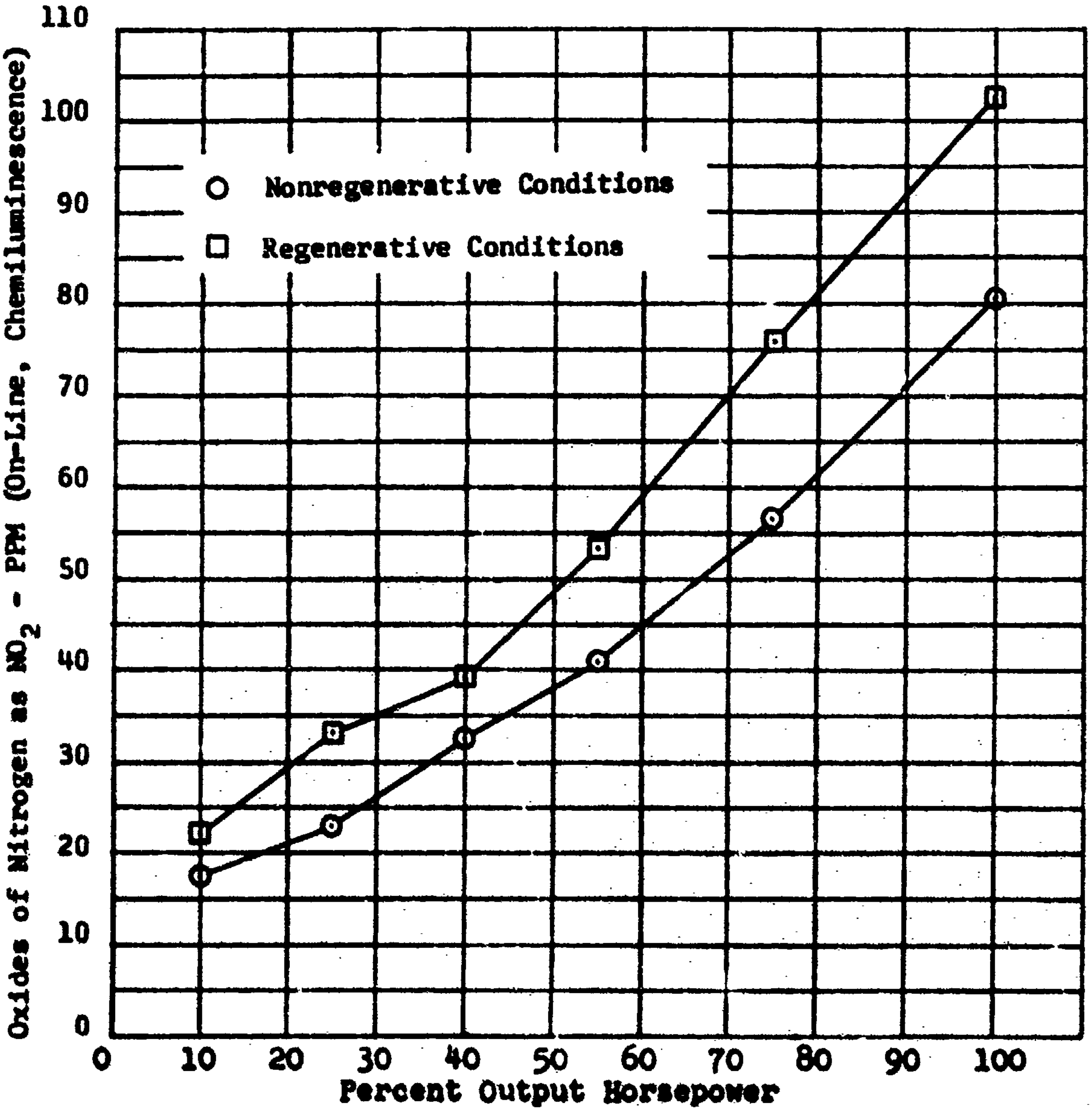

Figure 46. Conventional T63-A-5A Baseline Combustor Nitrogen Oxides Emission Test Rig Data.

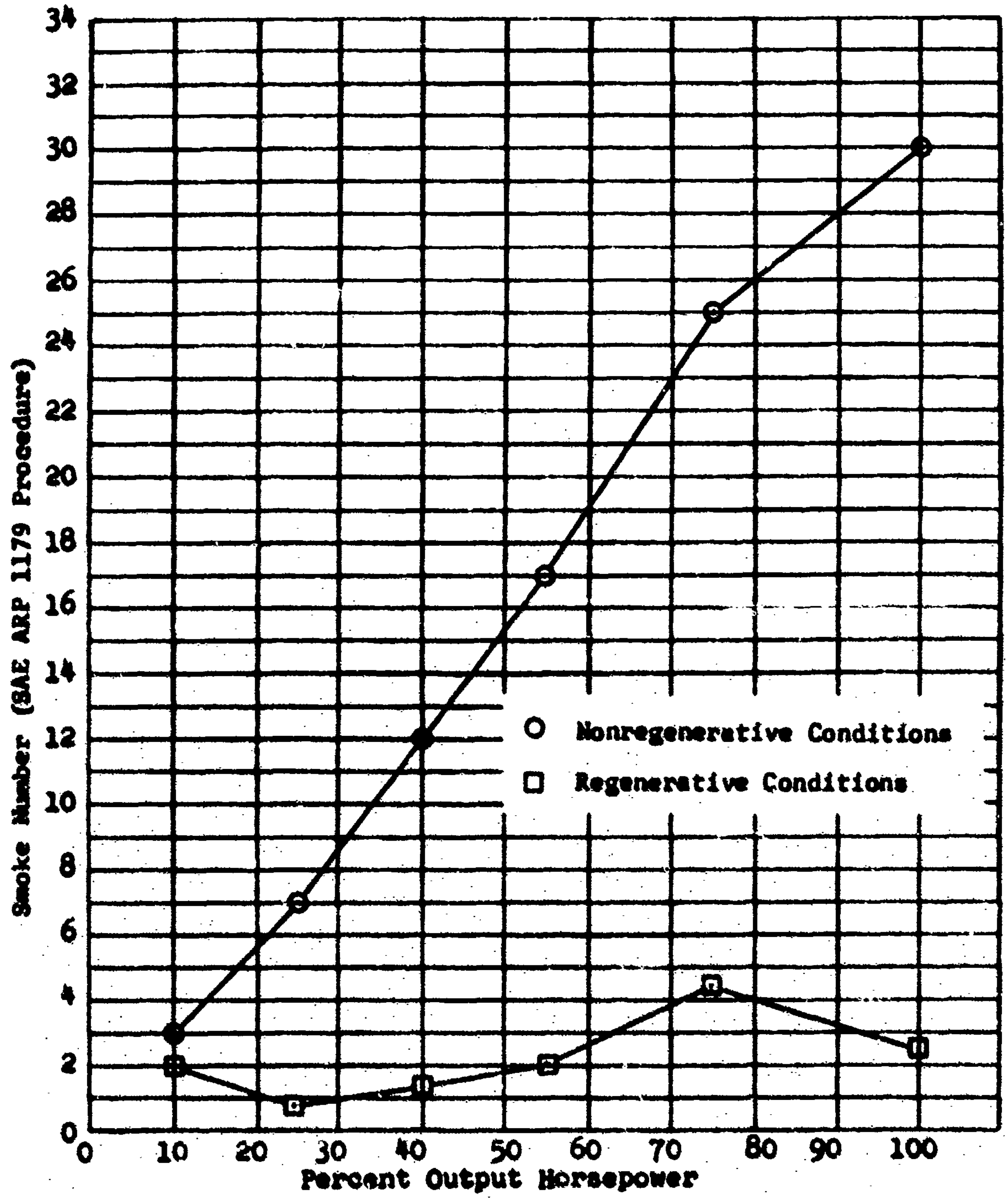

Figure 47. Conventional T63-A-5A Baseline Combustor Smoke Number Emission Test Rig Data.

TABLE XXV. LOW DUTY CYCLE EMISSIONS FOR THE BASELINE T63-A-5A COMBUSTOR LINER

Emission	Emission Index (lb emission/1000 lb fuel) Nonregenerative Combustor Conditions	Regenerative Combustor Conditions
C_xH_y	1.544	.378
CO	26.094	13.804
NO_x	5.068	8.412
Particulates	.239	.040
Total	32.945	22.634
Average Fuel Flow	140.65 lb/hr	97.64 lb/hr

lb/hr of total emissions at regenerative conditions, based on the LOH duty cycle.

The conventional T63-A-5A combustor baseline test was the first combustor operation in the T63 combustor rig located in the DDA Research Laboratory Combustion Test Facility. Toward the end of the contract a baseline combustor retest was conducted on the test rig with a different production T63-A-5A liner and a different production fuel injector. Certain constituent emission levels from this baseline combustor test differed substantially from the emissions from the initial test. Investigations after this baseline retest showed that the liner met production tolerances, but the fuel injector produced an unacceptably large variation in circumferential flow distribution. A new fuel injector was obtained and flow-bench tested, verifying that its performance was within specifications. Using the new fuel injector, a second retest of the conventional T63-A-5A combustor baseline was conducted. Comparison curves for the exhaust emissions produced during the initial baseline T63 combustor test and the second retest are plotted in Figures 48 through 51. Carbon monoxide and hydrocarbon emissions in Figures 49 and 48 repeated quite well. The nitrogen oxide emissions plotted in Figure 50 showed a definite decrease in the retest NO_x concentrations at each operating point.

By far the greatest differences were observed in the measured smoke numbers, see Figure 51. The recorded smoke/particulates from the retest were several times higher than the initial test values at all operating conditions. Table XXVI summarizes the emission index values computed for the initial test data (11/9/71) and the second retest data (7/31/72).

There were no conditions in the test rig, the test procedure, or the combustor hardware that would explain the change in NO_x and smoke. The good repeatability of the CO and C_xH_y emissions supports the contention that there were no major mechanical or aerodynamic differences between the tested combustors. Since the initial test was conducted in the late fall and retests were conducted in the summer, the effect of seasonal differences on the combustor inlet air or changes in the fuel during the interim might have explained the changes in NO_x and smoke. All combustor testing on this contract was performed with JP-4 fuel. The DDA Test Department had conducted emission measurements on another engine using JP-5 fuel, also in the winter and summer, and had observed similar differences in NO_x and smoke between the seasonal tests. It was therefore discounted that changes in fuel had caused the differences in NO_x and smoke.

It is known that water vapor has a significant effect on nitric oxide emissions.[32] With this phenomenon in mind, relative humidities for the test dates of the baseline combustor were obtained from DDA Facilities Department records and absolute atmospheric humidities

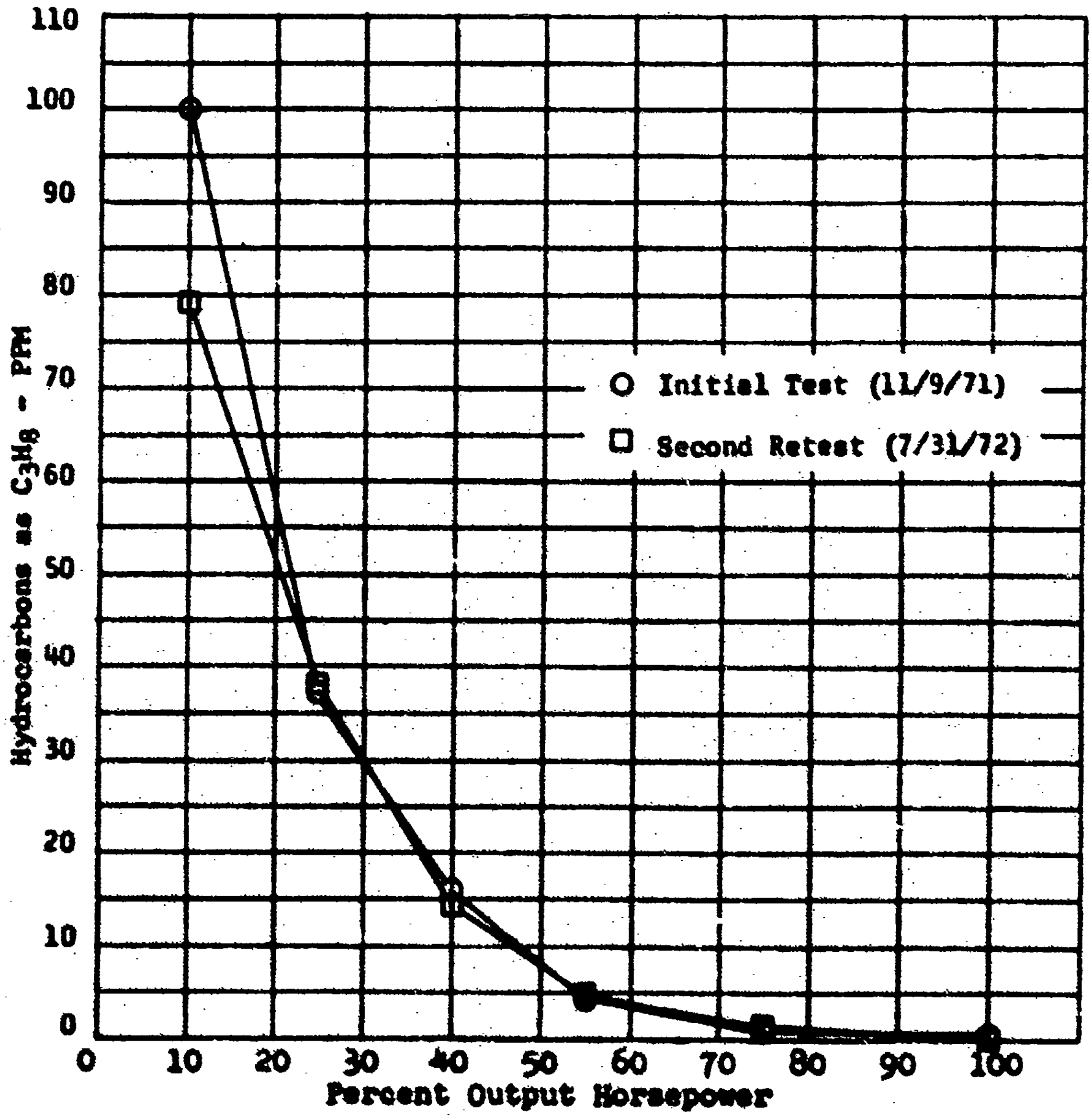

Figure 48. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Baseline Initial Test and Second Retest.

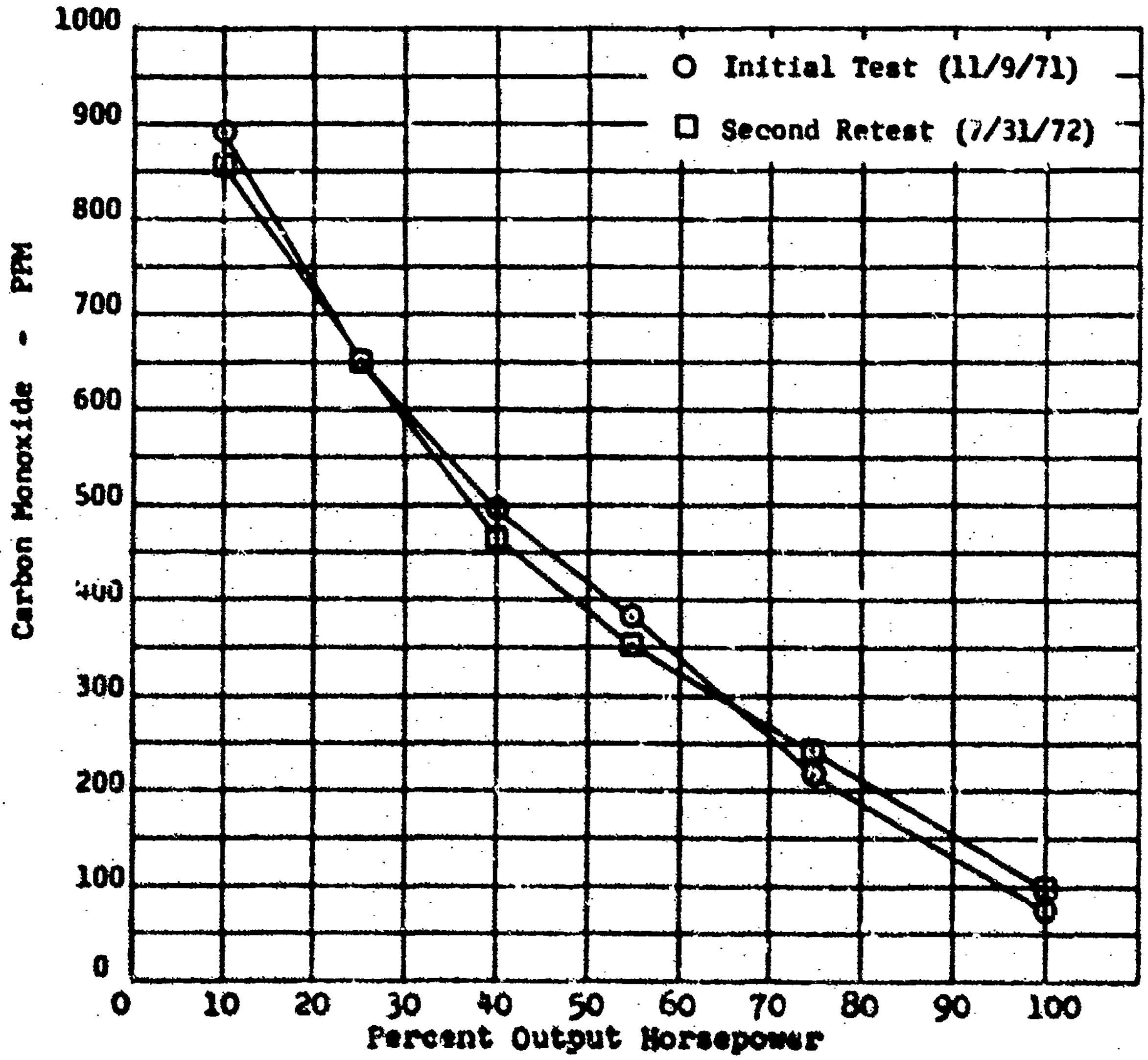

Figure 49. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Baseline Initial Test and Second Retest.

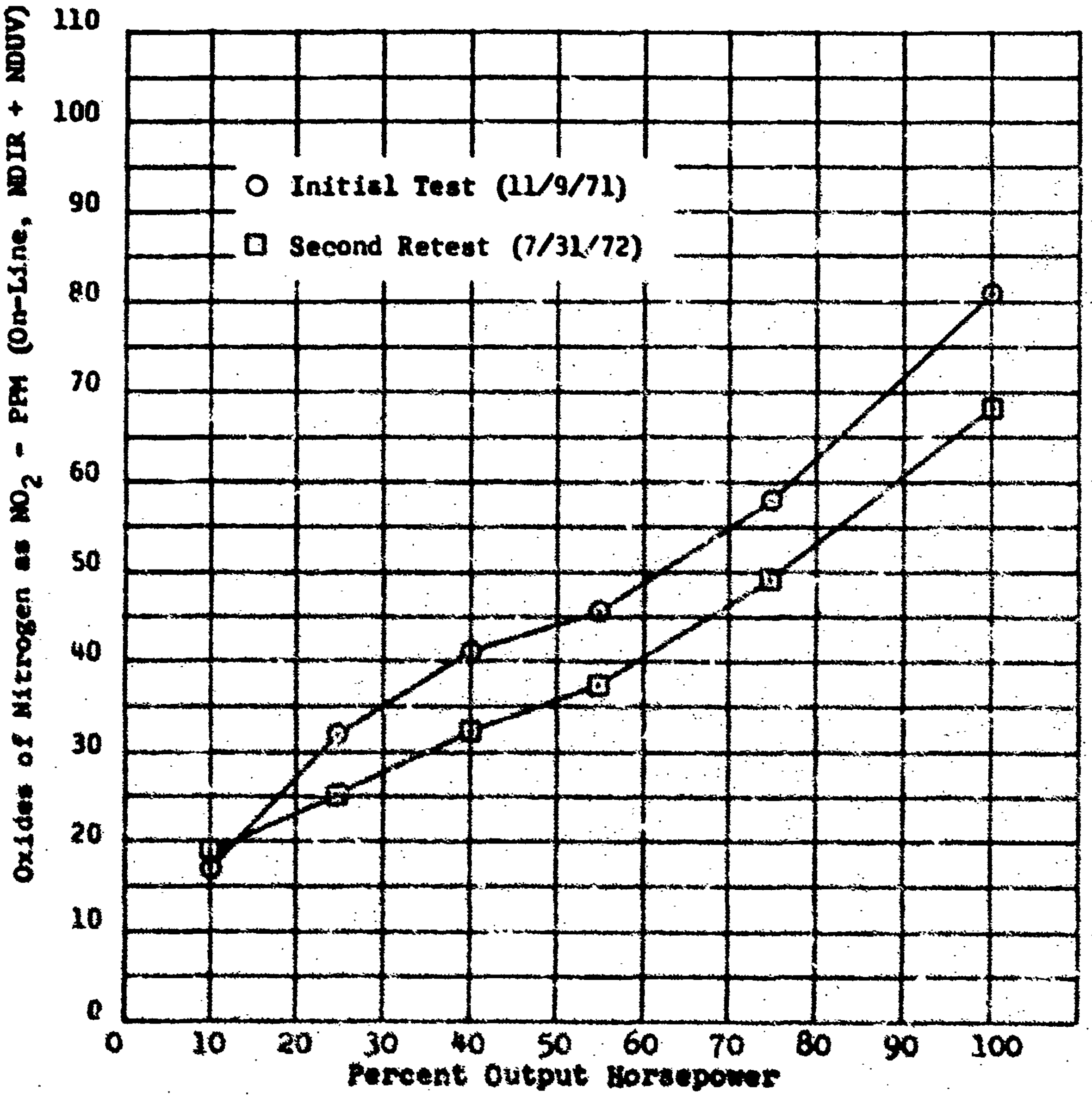

Figure 50. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Baseline Initial Test and Second Retest.

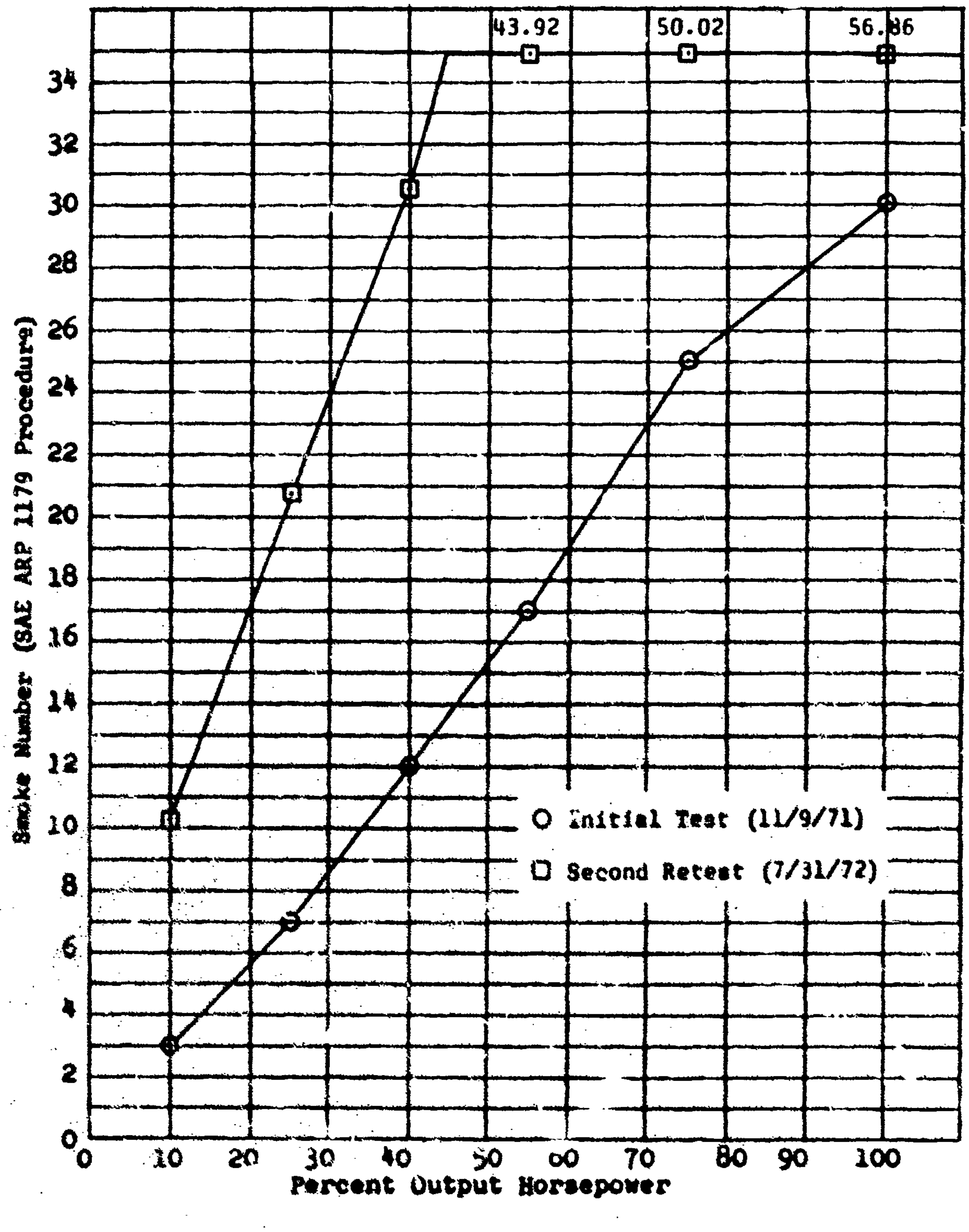

Figure 51. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Baseline Initial Test and Second Retest.

TABLE XXVI. EMISSION INDEX SUMMARY FOR CONVENTIONAL T63-A-5A COMBUSTORS

	Emission Constituent				
Test Date	C_xH_y	CO	NO_x *	Particulates	Total Emissions
Actual Emission Index (lb/1000 lb Fuel)					
11/9/71	1.544	26.094	5.068	.239	32.945
			5.189		33.066
7/31/72	1.323	25.080	4.241	1.100	31.744
			4.881		32.384
Relative Emission Index (% 11/9/71 Levels)					
11/9/71	100	100	100	100	100
			102		100
7/31/72	86	96	84	460	96
			96		98

* First NO_x Line is for On-Line NDIR + NDUV.
Second NO_x Line is for Saltzman.

experienced during each test were determined. It was found that the atmospheric absolute humidity during the initial baseline test was approximately 0.4% and during the second retest approximately 1.0%. The trend of NO_x decrease with increasing moisture content agrees with the predictions published by Moore.[32]

Although the fact remains to be proven in a controlled test, combustor inlet moisture content may have a direct effect on the smoke generated by a combustor liner. It is difficult to accept that the sole cause of the observed smoke increase in baseline retests was a small increase in moisture content of the inlet air. Future testing should be conducted with this observation in mind, and inlet combustor air moisture content should be measured in addition to the standard inlet parameters

Additional information concerning the conventional T63-A-5A combustor liner is presented in Appendix I.

Evaluation of Preliminary Combustors

The following seventeen combustors, each incorporating one or more selected low-emission concepts, were designed, fabricated and tested to obtain preliminary emission performance data:

- Extended Length
- Rich Primary Zone
- Air Blast/Air Assist
- Variable Geometry
- Early Quench
- Delayed Dilution
- Delayed/Annular Dilution
- Premix Cup/Gaseous Fuel
- Plug Flow/Canted Primary
- Tangential Swirl
- Swirl Dome
- Rich Premix/Swirl
- Pepper-Pot Dome
- Delayed Quench
- Premix/Prevaporization
- Prechamber
- Optimum Primary

The detail designs and experimental results for the above combustors are presented in Appendix II. In addition, the referenced DDA reports present even more details on each of the combustors.

The approach in this phase of the contract was to obtain a low-cost, rapid evaluation of each of the low-emission concepts. The best concept or concepts would then be designed into the final configuration(s) as discussed in the next section and Appendixes III and IV. The final concepts would be the ones specifically designed to meet the contract objectives using the information and technology obtained in this program phase.

All seventeen combustors had the same nominal diameter of 6.21 inches at the exit. The combustors were of two different lengths. Some of them were the conventional T63-A-5A length of 9.56 inches; the others were nominally 6 inches longer, or 15.56 inches in length. In the above list of seventeen combustors, the following four combustors were the conventional length:

- Rich Primary Zone
- Air Blast/Air Assist
- Delayed Dilution
- Delayed/Annular Dilution

The longer liners were selected to provide additional length to separate the primary, trim (intermediate), and dilution zones to reduce the problem of intermixing between the zones.

The low-emission concepts incorporated into each of the combustors are summarized in the following listing.

Combustor	Low-Emission Feature(s)
Extended Length	Increase residence time in the intermediate zone to consume the CO, C_xH_y, and carbon with only small increases in NO_x and thus reduce total emissions significantly.
Rich Primary Zone	Increase the primary zone equivalence ratio from conventional 0.77 to 1.0 and thus reduce the CO and C_xH_y with an increase in NO_x particulates.
Air Blast/Air Assist	Reduce fuel-rich pockets encountered with conventional pressure atomizing fuel injection and thus reduce particulate levels with only minor changes in other emissions.
Variable Geometry	Control the primary-zone fuel/air ratio to the optimum for minimum emissions over the LOH duty cycle, engine operating conditions, thus reducing CO and C_xH_y at low power and NO_x and particulates at high power. The primary zone equivalence ratio at maximum power could be varied from 0.466 to 1.54 compared to 0.77 for the conventional combustor.

Combustor	Low Emission Feature(s)
Early Quench	The primary holes were moved closer to the dome to reduce the primary-zone residence time. Reduction of time at high temperature should reduce the NO_x.
Delayed Dilution	Same concept as "Extended Length" combustor except somewhat less residence in the intermediate zone than the "Extended-Length" liner but more than in the T63-A-5A conventional combustor.
Delayed/Annular Dilution	Same emission reduction concept as the "Delayed Dilution". An annular dilution zone was incorporated to improve exit temperature profile.
Premix Cup/Gaseous Fuel	Incorporated four features: (1) fuel prevaporization, (2) fuel-air premix, (3) well-stirred reactor in primary zone, (4) rapid conversion to plug flow.
Plug Flow/Canted Primary	Well-stirred (mixed) primary to provide homogeneous combustion and rapid conversion to plug flow to consume the CO, C_xH_y and carbon.
Tangential Swirl	Improved mixedness in the primary zone by setting up strong recirculation loop in the primary zone by injecting the primary air tangentially on the wall at 45° upstream direction, thus reducing hot-spot (zone) temperatures and NO_x.
Swirl Dome	Swirl improves the mixedness and reduces the local hot-spot temperatures in the primary zone, thus reducing the concentrations of NO_x.
Rich Premix/Swirl	The same low-emission feature as the "Swirl Dome" except a premix cup was used to mix the fuel/air and partially vaporize the fuel prior to the main reaction zone. This would improve the flame homogeneity - reduce hot spots - and therefore reduce emissions. Additional features were fuel-rich (ϕ=2.0 at max. power) operation in the premix (precombustion) cup and convection

Combustor	Low Emission Feature(s)
	cooling instead of film cooling. The latter feature would eliminate the quenching of the CO, C_xH_y and C reactions in the coolant film.
Pepper-Pot Dome	Establish small-scale recirculation with rapid conversion to plug flow. Task 2 reaction kinetic studies had shown this would be an ideal condition for minimum CO, C_xH_y and NO_x emissions. Convection cooling in the primary zone instead of film cooling.
Delayed Quench	Just opposite to the "Early Quench", the primary holes were moved aft to increase primary-zone residence, which should reduce CO and C_xH_y but increase NO_x. Thus the optimum axial location of the primary holes could be defined for minimum emissions.
Premix/Prevaporization	Premix/prevaporization prior to the primary-zone reaction should improve the combustion-zone homogeneity and avoid fuel droplet combustion and the high, localized temperatures associated with droplet combustion.
Prechamber	Same low-emission features as the "Premix/Prevaporization" combustor except that the prechamber has swirl to entrain some of the combustion reaction products to assist in the prevaporization of the fuel. This feature is necessary to provide prevaporization at low combustor inlet temperatures below the fuel vaporization temperature.
Optimum Primary	The concept was to replace the conventional twelve holes in the primary section with six holes in a symmetric pattern with the same total hole area. Analytical studies indicated that the optimum number is six for maximum primary zone mixing and recirculation, thus reducing emissions by attaining more uniform combustion.

The seventeen combustors listed above were tested at primarily the T63-A-5A non-regenerative combustor operating conditions presented in Table IV. As shown in that table, six steady-state operating conditions were defined from idle through maximum power. Most of the above-listed combustors were tested at all six conditions, but a limited number of combustors were tested at fewer sets of conditions due to combustor operational problems. However, some of the combustors such as the "Variable Geometry Combustor" were tested at many variable-geometry settings and at both nonregenerative and regenerative conditions. Furthermore, some of the seventeen combustors were modified and retested.

Sixteen of the combustors were tested with JP-4 fuel; the other combustor, "Premix Cup/Gaseous Fuel," was tested with gaseous propane.

The experimental results from the seventeen preliminary combustors are presented in Appendix II. From the experimental data as presented in Appendix II, the total emission indexes were calculated for the seventeen preliminary low-emission combustors. The calculations were made for the previously defined LOH duty cycle and the T63 nonregenerative engine. These emission indexes were then compared with the baseline T63-A-5A combustor as shown in Table XXVII to determine relative potential for meeting contract emission reduction objectives. These objectives, as previously defined, are to reduce the total emissions 50% without an increase in any individual emission. As shown in Table XXVII , eight of the preliminary combustors met the 50% total emission reduction objective but only the "Prechamber" combustor met the second objective of no increase in the individual emissions. However, a combination of some of the separate low-emission features in the seventeen preliminary combustors could be combined into a combustor to meet the contract objectives. This in fact was done, and two final combustors were selected from this preliminary evaluation for experimental testing. These were the "Prechamber" and "Modified Conventional". The "Modified Conventional" incorporated four of the low-emission features from this phase of the program. These features were air-blast fuel injection, variable geometry, delayed dilution, and convection cooling. The design and experimental evaluation of these final low-emission combustors are discussed in the next section. However, before proceeding to the discussion of the final combustors, a brief disucssion will be presented on the preliminary low-emission combustors.

Two of the combustors, the "Extended Length" and "Delayed Dilution," were designed to increase the residence time in the intermediate zone - the zone between the primary holes and dilution holes. The intermediate zone length was 1.5 inches, 7.5 inches, and [illegible].76 inches for the T63-A-5A, "Extended Length" and "Delayed Dilution" combustors. The total respective lengths for the combustors were

TABLE XXVII. RELATIVE EMISSION INDEX PERFORMANCE OF PRELIMINARY LOW-EMISSION COMBUSTORS

	RELATIVE EMISSION INDEX, %					
COMBUSTOR	C_xH_y	CO	NO_x	PARTICU-LATES	TOTAL EMISSIONS	CYCLE POINTS
T63-A-5A Baseline	100	100	100	100	100	5
Extended Length	44	33	124	14	48	5
Rich Primary Zone	63	65	110	321	73	5
Air Blast/Air Assist						
• DDA Air Blast	136	105	108	15	106	5
• Ex-Cell-O Air Blast	155	100	87	36	100	5
• Ex-Cell-O Air Assist	216	102	73	74	103	5
Variable Geometry						
• Constrained	35	56	103	22	62	5
• Unconstrained	20	32	121	29	45	5
Early Quench	248	70	128	74	84	4
Delayed Dilution	65	54	99	41	62	5
Delayed/Annular Dilution	77	60	91	156	66	5
Premix Cup/Gaseous Fuel	1800	211	135	a	440	1
Plug Flow/Canted Primary						
• Initial Design	315	108	100	181	117	5
• Mod. "A"	55	47	116	709	63	5
Tangential Swirl	1380	88	106	17,090	285	1
Swirl Dome	52	32	116	185	47	5
Rich Premix/Swirl	3	11	121	58	28	5
Pepperpot Dome	24	34	133	1	49	5
Delayed Quench	54	52	109	541	[illegible]	5
Premix/Prevap.	106	50	100	a	58	1[b]
Prechamber						
• Initial Design	92	37	50	0	41	5[c]
• Richer Primary	52	24	70	0	32	5[d]
Optimum Primary	27	29	126	33	44	5

a No data taken

b Adjusted design point

c Based on extrapolated data for idle and max. power

d Based on extrapolated data for max. power

9.56 inches, 15.56 inches, and 9.56 inches. There was a significant effect on emissions by changing the intermediate zone length. The emission data in Table XXVII shows that the total emissions from the T63-A-5A combustor could be reduced by 38% by the simple modification of moving the dilution holes. This was accomplished within the same total combustor liner length, and there was no increase in any of the individual pollutants. A further reduction in total emissions was obtained by increasing the intermediate zone length to 7.5 inches, but to achieve this the total liner length was increased 6 inches.

The effect of enrichening the primary zone in the "Rich Primary Zone" combustor was as predicted. The conventional T63-A-5A operates at 0.77 equivalence ratio in the primary zone at maximum power. Increasing the primary zone equivalence ratio to 1.0 caused a decrease in CO and C_xH_y but with a corresponding increase in NO_x and particulates. The total emissions were reduced 27%.

The main advantage of the "Air-Blast/Air-Assist" fuel injectors was a reduction in smoke. In general, the hydrocarbons increased and the CO stayed approximately the same. The NO_x decreased slightly due to reduction in reaction (flame) temperature and improved homogeneity. Therefore, if air-blast or air-assist fuel injectors are compared with high-performance pressure atomizer fuel injectors, the principal payoff in emissions will be reduction in smoke. The total emissions as shown in Table XXVII may actually increase.

There was only a small reduction in total emissions from the "Variable Geometry" combustor for the selected LOH duty cycle. The total emissions were reduced only 6% compared to the same length combustor ("Extended Length"), shown in Table XXVII. This 6% reduction compares to a predicted reduction of 12% in Task 2. This small payoff is unique to the selected LOH duty cycle. If another duty cycle is selected, the emission reduction would be much greater. For example, if a duty cycle is selected which operates 50% of the time at idle and 50% of the time at maximum power, the following emission reductions are obtained from "Variable Geometry" as compared to the same length, "Extended Length", combustor:

C_xH_y ------------------ 61% reduction

CO -------------------- 50% reduction

NO_x ------------------- 17% reduction

Total Emission -------- 38% reduction

Even more dramatic would be a duty cycle in which the only emission control requirements are CO and C_xH_y at idle power and NO_x at maximum power. For this type of operation, variable geometry reduced

the C_xH_y by 67%, the CO by 58%, and the NO_x by 25%. These reductions were compared to the "Extended-Length Combustor", which already had significantly lower emissions than the conventional T63-A-5A combustor. Compared to the conventional T63-A-5A, the "Variable-Geometry" combustor reduced the C_xH_y by 84% and the CO by 77%. However, the NO_x increased by 11% due to the longer residence time at intermediate temperature. Variable dilution geometry can be adapted to any combustor tested during this program. The fixed geometry combustors which produced substantial emission reduction, such as the "Rich Premix/Swirl" and the Prechamber combustors, could have variable geometry added to the dilution zone and realize further emission reductions.

The effect of the axial location of the primary holes was investigated in two combustors. In the "Early-Quench" combustor, the primary holes were moved forward 0.64 inches; in the "Delayed Quench" combustor, the primary holes were moved aft 1.10 inches. Except for these changes, they were both exactly the same as the "Extended-Length" combustor, and the data should be compared with it. As shown in Table XXVII, the total emissions increased by moving the primary holes either forward or aft. Therefore, the optimum axial location was approximately that of the conventional T63-A-5A combustor. This optimum axial location was approximately one primary zone radius downstream from the dome. The axial location of the primary holes does have a significant effect on the total emission and on some of the individual emissions, as shown in Table XXVII, and it is important to establish the best axial location for the primary holes in low-emission combustors.

One of the combustors, "Optimum Primary", was designed to investigate the effect of the number of primary holes. Analytical studies had predicted that the mixing and primary-zone recirculation would improve by using six primary holes instead of the twelve primary holes used in the conventional T63-A-5A. The "Optimum-Primary" combustor was the same as the "Extended-Length" combustor except that the "Optimum-Primary" combustor had six primary holes instead of twelve. As shown in Table XXVII, there was a small reduction in total emissions of 8% compared to the "Extended-Length" combustor. Therefore, the number of primary holes does have a small effect, but it is not as significant as the axial location of the primary holes.

Four of the combustors incorporated various design approaches to prevaporize the fuel and premix the fuel and primary air. These four were: "Premix/Prevaporization", "Rich Premix/Swirl", "Premix Cup/Gaseous Fuel", and "Prechamber." As shown in Table XXVII, the "Prechamber" was the best of these, followed closely by the "Rich Premix/Swirl" combustor. Theoretically, the premix/prevaporization combustors should offer the best emission reduction potential of any of the concepts tested in this program. Although they did not attain the quantitatively predicted reduction, a significant reduction was demonstrated, and the reduction was better than it was with any of the other concepts. The main problem with these systems is to design a practical system to vaporize the fuel at low combustor inlet tem-

peratures. Two potential solutions are to (1) recirculate some of the combustion reaction gases either internally or externally to increase the average inlet temperature or (2) prevaporize the fuel by indirect heat exchange such as an immersed fuel line in the primary zone. The best approach tested was the "Prechamber", which internally recirculates some of the combustion reaction gases.

Four Combustors designed to provide intense primary-zone mixedness, recirculation, and rapid conversion to plug flow were:

- "Plug Flow/Canted Primary"
- "Tangential Swirl"
- "Swirl Dome"
- "Pepper-Pot Dome"

The analytical studies in Task 2 had shown that intense recirculation with rapid conversion to plug flow should reduce the emissions. However, this is difficult to achieve in a practical, low-pressure-loss system. Two of the four systems of this type tested in this program showed some potential. These were the "Plug Flow/Canted Primary" and the "Pepper-Pot Dome" combustors. As shown in Table XXVII, the Pepper-Pot Dome" combustor had the least smoke (particulates of any of the seventeen combustors except the "Prechamber" combustor. Further development of these two approaches would probably lead to further reductions in the emissions. However, other concepts such as the "Prechamber" demonstrated greater potential in these preliminary experiments. Development of more than two concepts was beyond the scope of this program.

Another low-emission feature incorporated into several of the combustors was convection cooling instead of the conventional film cooling. Although this feature was not investigated independently, experiments in other low-emission programs at DDA have shown that the CO, C_xH_y, and particulate emissions are reduced by the elimination of film cooling. With film cooling, the CO, C_xH_y and C oxidation reactions quench in the film cooling air. This is a more severe problem in annular combustors than in the can combustors tested in this program. In annular combustors, it will be even more important to use convection cooling instead of film cooling to obtain low emissions.

Based upon the experimental results in this phase of the program, two combustor approaches were selected for final design and experimental evaluation. One of these represented "near-term" potential in which modifications could be made to conventional combustors, and the other approach ("Prechamber") offers greater emission reduction potential but it will require more development time. The design, fabrication, and experimental evaluation of these two final combustors ("Modified Conventional" and "Prechamber") are discussed in the next section of this report.

Evaluation of Final Combustors

Two final combustor configurations were selected from the test results of the seventeen preliminary combustors evaluated during the first part of Task 3. These two final combustors were identified as the Final Prechamber Combustor Liner and the Final Modified Conventional Combustor Liner.

Final Prechamber Combustor Liner

Two of the preliminary low-emission combustor concepts which showed substantial emission reductions were the Rich Premix/Swirl Combustor Liner and the Prechamber Combustor Liner. Both of these combustors utilized a premix cup with a swirl dome, a sudden expansion into the reaction zone, convection cooling of the reaction zone, extended overall length, and delayed dilution. One fundamental difference between these two preliminary liners was the method of fuel injection. The Rich Premix/Swirl Combustor used a conventional T63 pressure-atomizing fuel injector, centrally located in the swirler dome of the premix cup. The Prechamber Combustor injected the liquid fuel onto the inside wall of the premix cup or vaporizer tube and relied upon the high-velocity swirl air and combustion heat to vaporize the fuel off the wall.

Being quite similar in several respects, these two premix cup preliminary combustors were combined into a single final design combustor called the Final Prechamber Combustor Liner. As can be seen in the photograph in Figure 52, both the pressure atomizer and the wall fuel-film injection methods were incorporated into the premix cup or vaporizer tube dome end of the liner. The overall length of the Final Prechamber was reduced from the preliminary combustor length to be only 3 inches longer than the conventional T63 combustor. This reduction in length was obtained by reducing the combustor length between the reaction-zone row of holes and the dilution row of holes. The reaction-zone liner diameter was increased from 5.30 inches to 6.34 inches to provide more combustion volume and to increase the inlet air velocity between the liner and the outer combustor case to create a convection cooling region along the liner reaction zone. Delayed dilution was retained for consumption of the carbon monoxide, hydrocarbons, and particulates.

A series of modifications on the Final Prechamber Combustor was made in an attempt to further reduce emissions and improve combustor performance. These modifications are summarized in Table XXVIII. The first rework of the Final Prechamber was to remove 1.50 inches of axial length from the vaporizer tube and to add 1.50 inches downstream of the dilution holes, see Figure 53. It was intended that the reduction in the vaporizer tube length

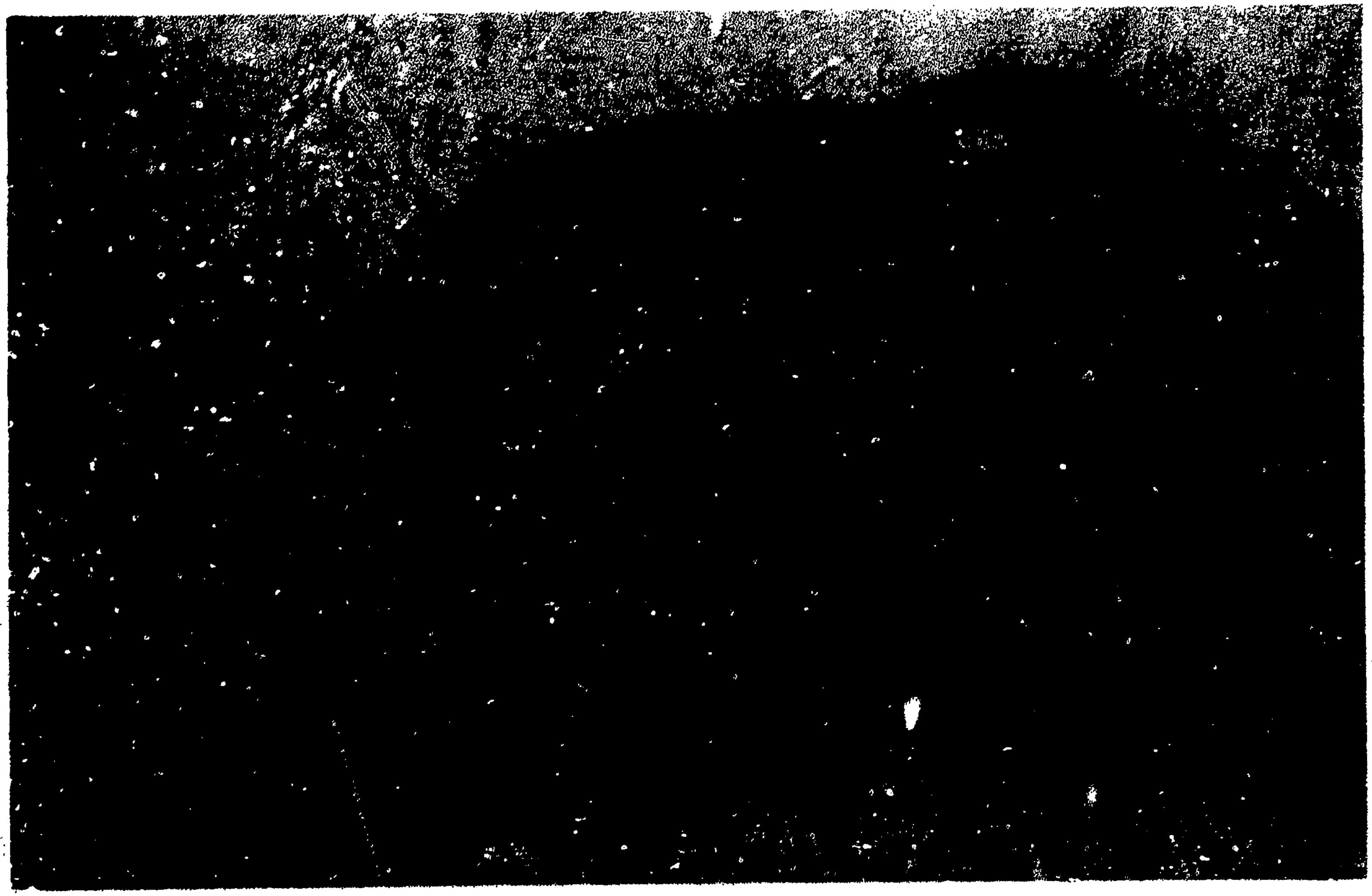

Figure 52. Final Low-Emission Prechamber Combustor Liner, Initial Configuration.

TABLE XXVIII. FINAL-DESIGN PRECHAMBER COMBUSTORS, DESIGN SUMMARY

Design Parameter	Initial Design	Mod. "A"	Mod. "B"	Mod. "C"	Mod. "D"
Hole Size (inches)					
Fuel Film Injector (16)	.013	.013	.021*	.021	.021
Reaction Zone (12)	.360	.360	.297*	Closed*	Closed
Dilution Zone (6)	1.344	1.344	1.310*	1.310	1.310
Length (inches)					
Overall	12.670	12.670	12.670	12.670	12.670
Vaporizer Tube	4.445	2.945*	4.500*	4.500	4.500
Vaporizer Tube-Reaction Holes	1.500	1.500	1.400*	1.400	1.400
Reaction Holes-Dilution Holes	3.730	3.730	3.730	3.730	3.730
Dilution Holes-Liner End	2.100	3.600*	2.100*	2.100	2.100
Diameter (inches)					
Swirler I.D.	1.670	1.670	2.410*	2.410	2.410
Swirler O.D.	2.960	2.960	3.680*	3.680	3.680
Vaporizer Tube I.D.	3.080	3.080	3.800*	3.800	3.800
Reaction Zone O.D.	6.340	6.340	6.340	6.340	6.340
Dilution Holes I.D.	5.640	5.640	5.640	5.640	5.640
Exhaust O.D.	6.210	6.210	6.210	6.210	6.210
Fuel Injection Mode Tested					
Pressure Atomizer	Yes	Yes	Yes	NO*	NO
Wall Fuel Film	Yes	Yes	Yes	Yes	Yes
Vaporizer Tube Centerbody	NO	NO	NO	NO	Yes*

*Indicates change from previous design.

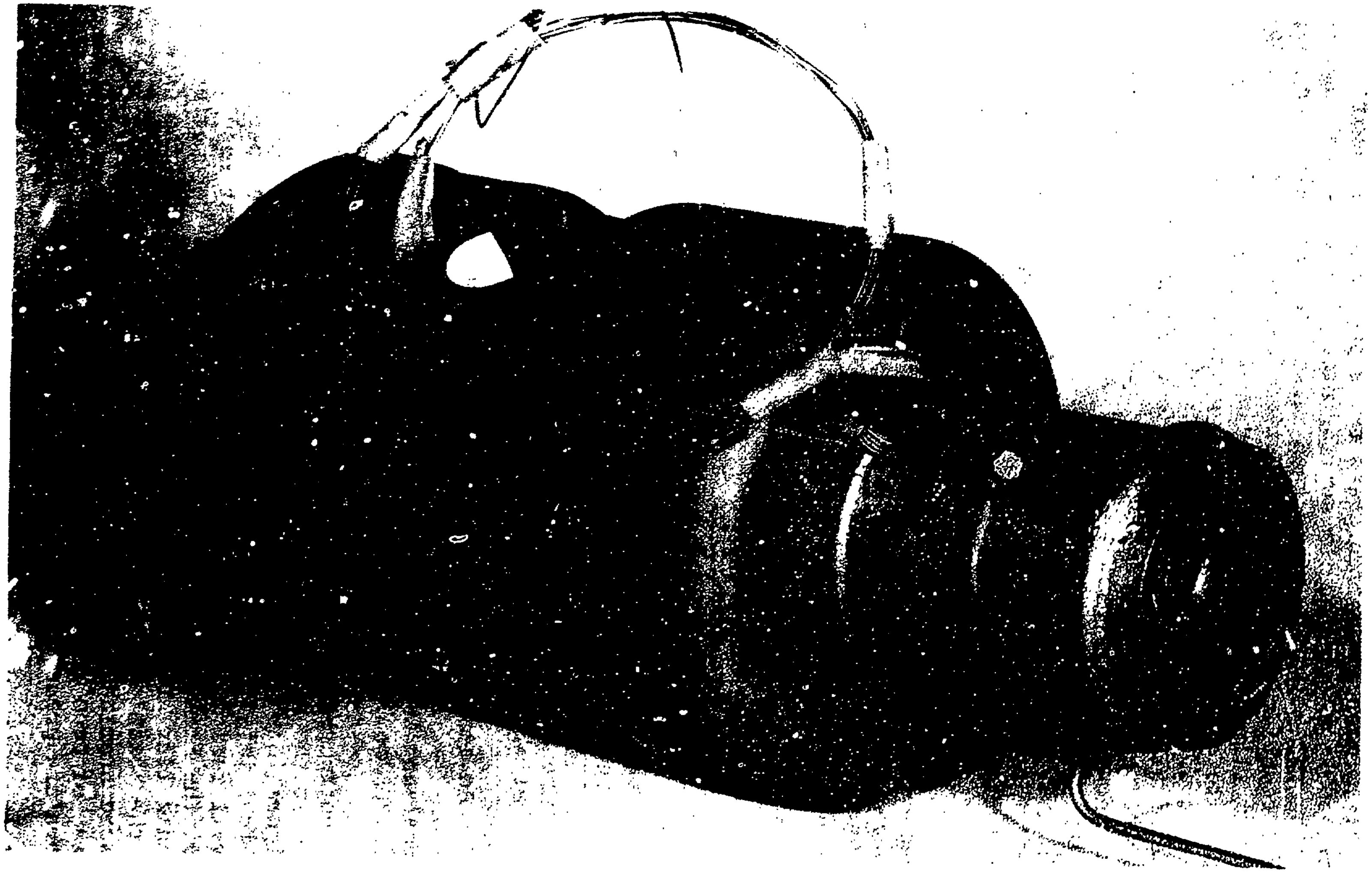

Figure 53. Final Low-Emission Prechamber Combustor Liner, Modification "A".

would allow more combustion gases to be pumped up the swirl vortex and be mixed with the swirler air. The increased vaporizer tube recirculation would then raise the air-combustion gas mixture temperature and provide better fuel vaporization of the wall fuel film. The added length downstream of the dilution zone was to allow additional volume prior to the combustor exit for improvement of the exhaust temperature profile. This version of the Final Prechamber combustor liner, Modification "A", produced the best emission performance with acceptable combustor performance of all versions operated on the pressure atomizer fuel injector.

Because the first two versions of the Final Prechamber combustor liner failed to operate satisfactorily on wall fuel film injection, the combustor progressed through a major redesign and two minor modifications, resulting in Modification "D". This Final Prechamber combustor configuration was judged to be the best overall version operating on the wall fuel film injection system. The changes made to the Final Prechamber combustor from Modification "A" through Modification "D" were the following:

1. The vaporizer tube section was completely redesigned to increase the swirler airflow, increase the swirler hub-to-tip diameter ratio, and increase the vaporizer tube length.

2. The wall fuel film injector orifice diameters were increased from 0.013 inch to 0.021 inch.

3. The airflow through the reaction zone holes was eliminated.

4. An aerodynamic centerbody was added at the swirler hub.

External and internal photographs of the Final Prechamber Modification "D" combustor liner are presented in Figures 54 and 55.

Each configuration of the Final Prechamber combustor liner was tested at the six nonregenerative operating conditions. Three configurations were operated on the centerpoint pressure atomizer fuel injector, and all five configurations were operated on the wall fuel film injection system. Detailed test results for all of the Final Prechamber combustor testing are documented in Appendix III. The following paragraphs will present the data from the "best" Final Prechamber configuration operating on pressure atomizer and on the wall fuel film. Emission index summaries of each fuel injection mode of the Final Prechamber combustors are presented in Tables XXIX and XXX.

Final Prechamber combustor liner Modification "A" was the configuration producing the best overall performance for pressure

Figure 54. Final Low-Emission Prechamber Combustor Liner, Modification "D" External View.

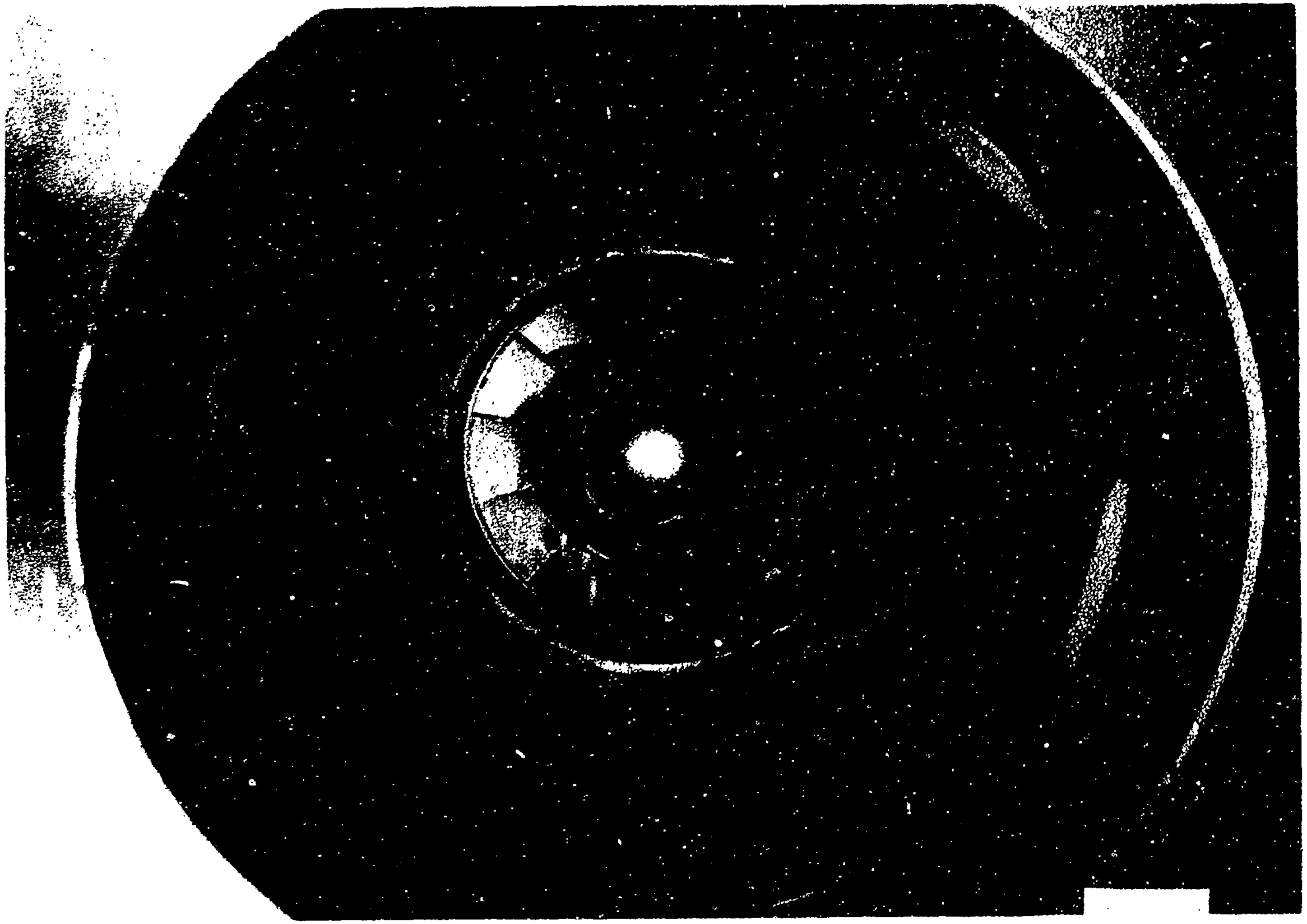

Figure 55. Final Low-Emission Prechamber Combustor Liner, Modification "D" Internal View.

TABLE XXIX. EMISSION INDEX SUMMARY FOR T63 BASELINE AND FINAL PRECHAMBER COMBUSTORS

Combustor Tested	C_xH_y	CO	NO_x	Particu-lates	Total Emissions
EMISSION INDEX (lb/1000 lb fuel)					
• Baseline	1.544	26.094	5.068	.239	32.945
• Final Prechamber-Pressure Atomizer					
Initial Design	.039	10.608	4.611	.128	15.386
Modification "A"	.025	10.292	4.300	.086	14.703
Modification "B"	.180	8.415	4.762	.902	14.259
RELATIVE EMISSION INDEX (%)					
• Baseline	100	100	100	100	100
• Final Prechamber-Pressure Atomizer					
Initial Design	2	41	91	54	47
Modification "A"	2	39	85	36	45
Modification "B"	12	32	94	377	43

TABLE XXX. EMISSION INDEX SUMMARY FOR T63 BASELINE AND FINAL PRECHAMBER COMBUSTORS

Combustor Tested	C_xH_y	CO	NO_x	Particu-lates	Total Emission
EMISSION INDEX (lb/1000 lb fuel)					
• Baseline	1.544	26.094	5.068	.239	32.945
• Final Prechamber-Wall Fuel Film					
Initial	.126	13.247	4.732	.337	18.442
Mod. "A"	.176	10.910	4.378	.274	15.738
Mod. "B"	2.077	13.810	4.092	.022	20.001
Mod. "C"	2.119	12.834	3.670	.007	18.630
Mod. "D"	1.033	11.947	4.584	.000	17.564
RELATIVE EMISSION INDEX (%)					
• Baseline	100	100	100	100	100
• Final Prechamber-Wall Fuel Film					
Initial	8	51	93	141	56
Mod. "A"	11	42	86	115	48
Mod. "B"	1[illegible]	53	81	9	61
Mod. "C"	137	49	72	3	57
Mod. "D"	67	46	90	0	53

atomizer fuel injection. The exhaust emissions, pressure loss, and temperature profile for this combustor are summarized in Table XXXI. The exhaust emissions are plotted with the conventional T63-A-5A baseline combustor in Figures 56 through 59.

Due to a poor exhaust temperature profile at the higher power levels, this Prechamber combustor could not be operated at 100% power conditions. As shown in Figure 56, hydrocarbon emissions remained below 1.0 ppm at all conditions tested. The carbon monoxide emissions plotted in Figure 57 were very low at idle and show a slow increase in concentration with increasing power conditions. Nitrogen oxide emissions seen in Figure 58 were also below conventional T63 NO_x concentrations. The smoke numbers in Figure 59 reveal that this combustor produced no smoke below the 40% power level. It can be observed in Figure 60 how the temperature profile deteriorated in the Final Prechamber combustor as the power level increased. Because of this worsening profile, maximum power data could not be obtained.

Total emissions for the Prechamber Modification "A" combustor were reduced below those of the initial design. Compared to the conventional T63 combustor, the pressure atomizer gave a 55% total reduction with no constituent increase. Extrapolations of emission concentrations at 100% power were made to permit the computation of total duty cycle emissions. Maximum power emissions accounted for only 5% of the cycle operating time; these extrapolations, if conservatively made, should not produce misleading total duty cycle results.

The Final Prechamber combustor which performed best overall when operating on wall fuel film injection was Modification "D". Closing the reaction zone holes and adding a vaporizer tube centerbody made definite improvements in combustor operation. The test rig data for Modification "D" are summarized in Table XXXII. A poor exhaust temperature profile on this combustor, as in most of the previous configurations, required that the testing be restricted to only the lowest five operating conditions. This combustor configuration maintained hydrocarbon concentrations below the baseline T63 combustor levels, see Figure 61. The two previous Prechamber configurations produced high levels of hydrocarbon emissions. Carbon monoxide emissions are plotted in Figure 62. These emission levels were well below the baseline concentrations. Nitrogen oxide emissions in Figure 63 were only slightly lower than those from the conventional T63-A-5A. The CO vs NO_x tradeoff curves in Figure 64 further illustrate the emission reductions achieved in the Modification "D" combustor.

Smoke/particulates from Modification "D" as shown in Figure 65

TABLE XXXI. FINAL LOW-EMISSION PRECHAMBER COMBUSTOR LINER MODIFICATION "A", OPERATING ON PRESSURE ATOMIZER, NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE

	Cycle Point					
	1	6	5	4	3	2
Emissions						
CO (ppm)	83.8	116.2	135.2	166.8	181.3	158.7*
H/C (ppm)	.7	.2	.7	.1	.1	.1*
NO_x (On-Line, NDIR & NDUV) (ppm)	19.0	23.1	32.7	38.7	48.1	50.5*
NO_x (Saltzman) (ppm)	12.0	24.0	35.7	46.6	62.5	72.9*
Smoke Number	.00	.00	.00	2.95	11.2	11.0*
Pressure Loss (%)	5.86	5.64	5.76	5.83	5.66	5.21*
Temp. Profile (T_{max}/T_{avg})	1.133	1.141	1.154	1.150	1.170	1.222*

*Not True Cycle Point 2. Fuel-Air Ratio Limited to .0185 due to BOT Hot Spots.

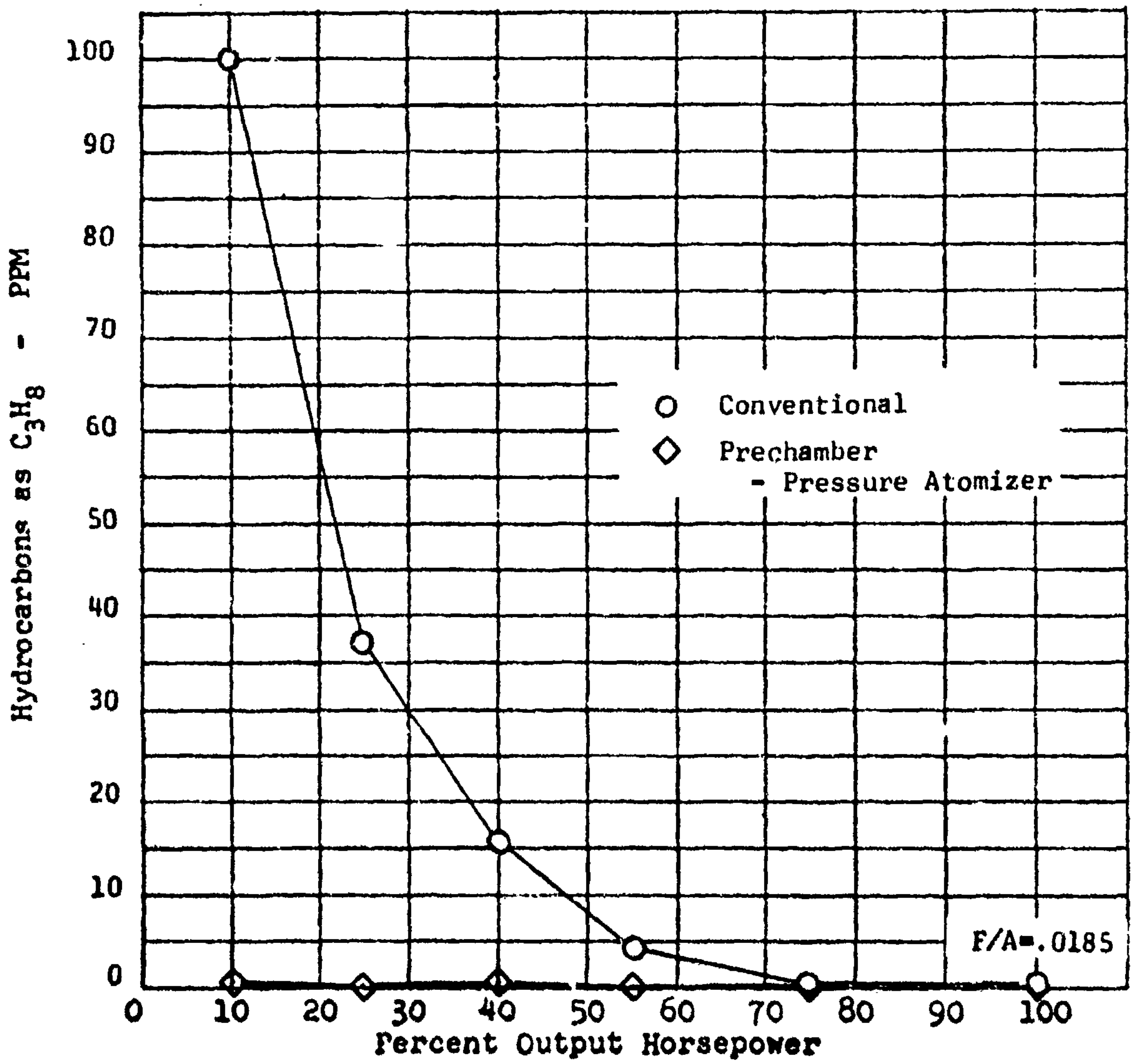

Figure 56. **Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Comparison for Final Prechamber Modification "A" Combustor Operating on Pressure-Atomizing Injection And Baseline T63-A-5A Combustor.**

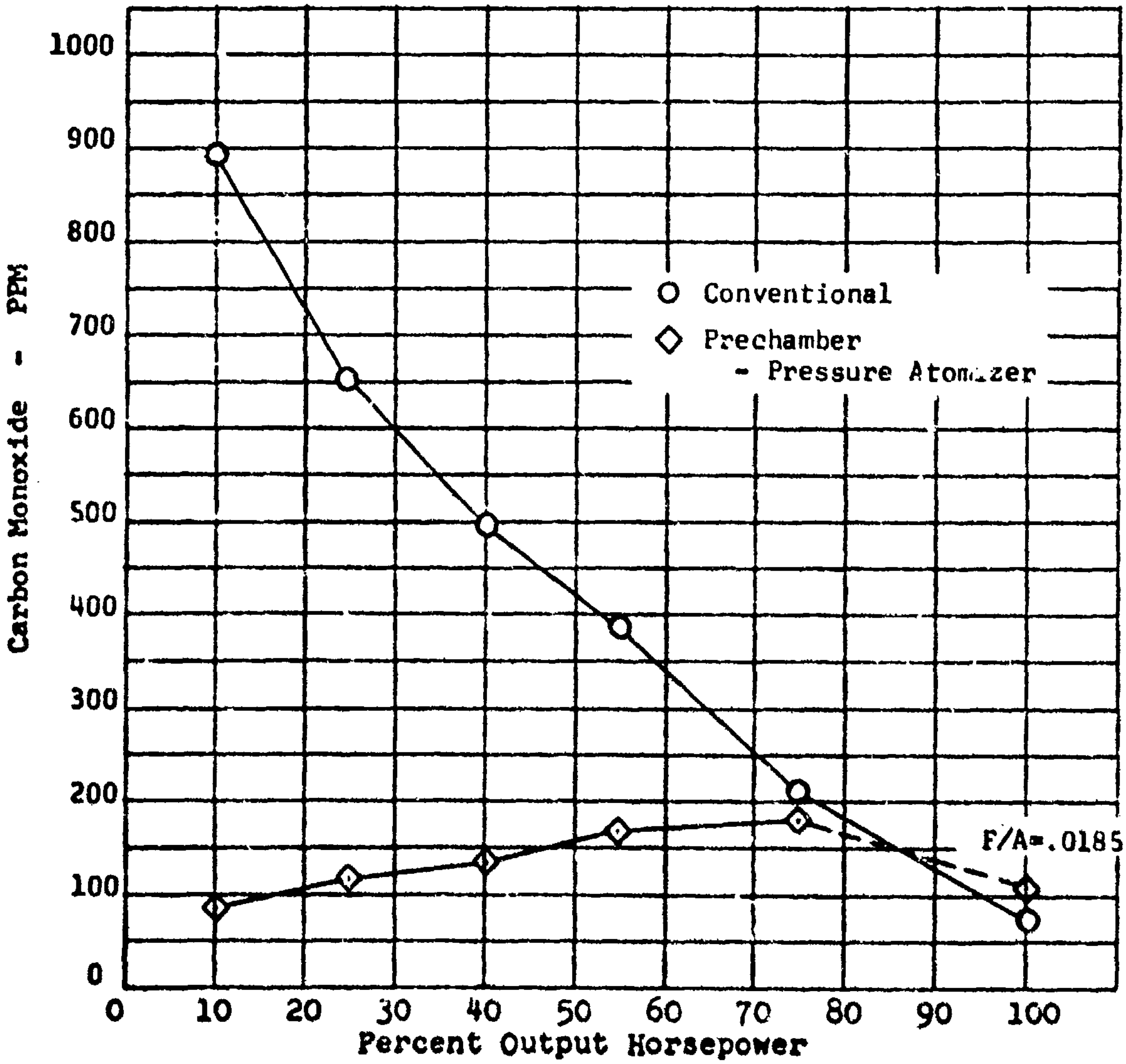

Figure 57. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Final Prechamber Modification "A" Combustor Operating on Pressure-Atomizing Injection And Baseline T63-A-5A Combustor.

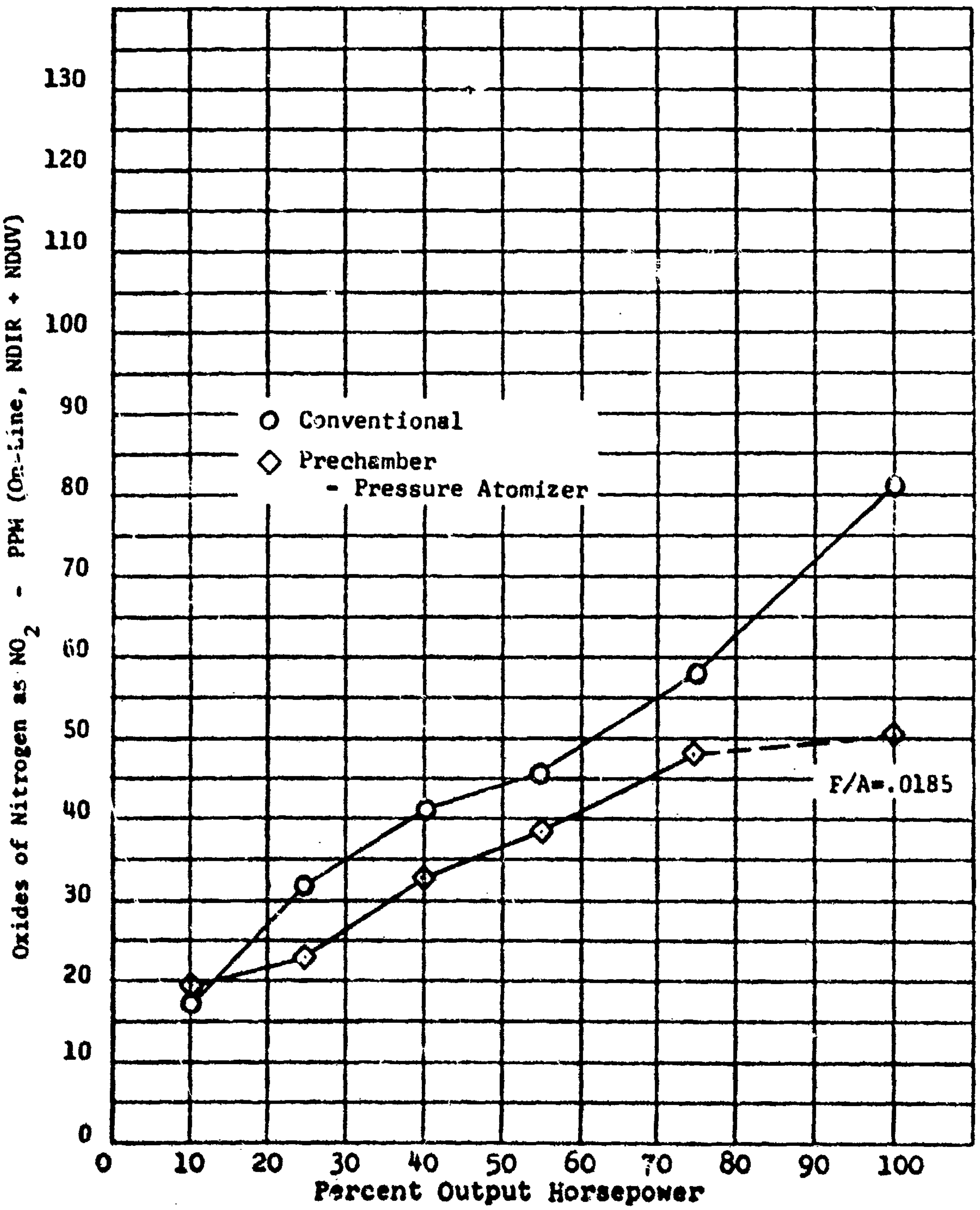

Figure 58. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Final Prechamber Modification "A" Combustor Operating on Pressure-Atomizing Injection And Baseline T63-A-5A Combustor.

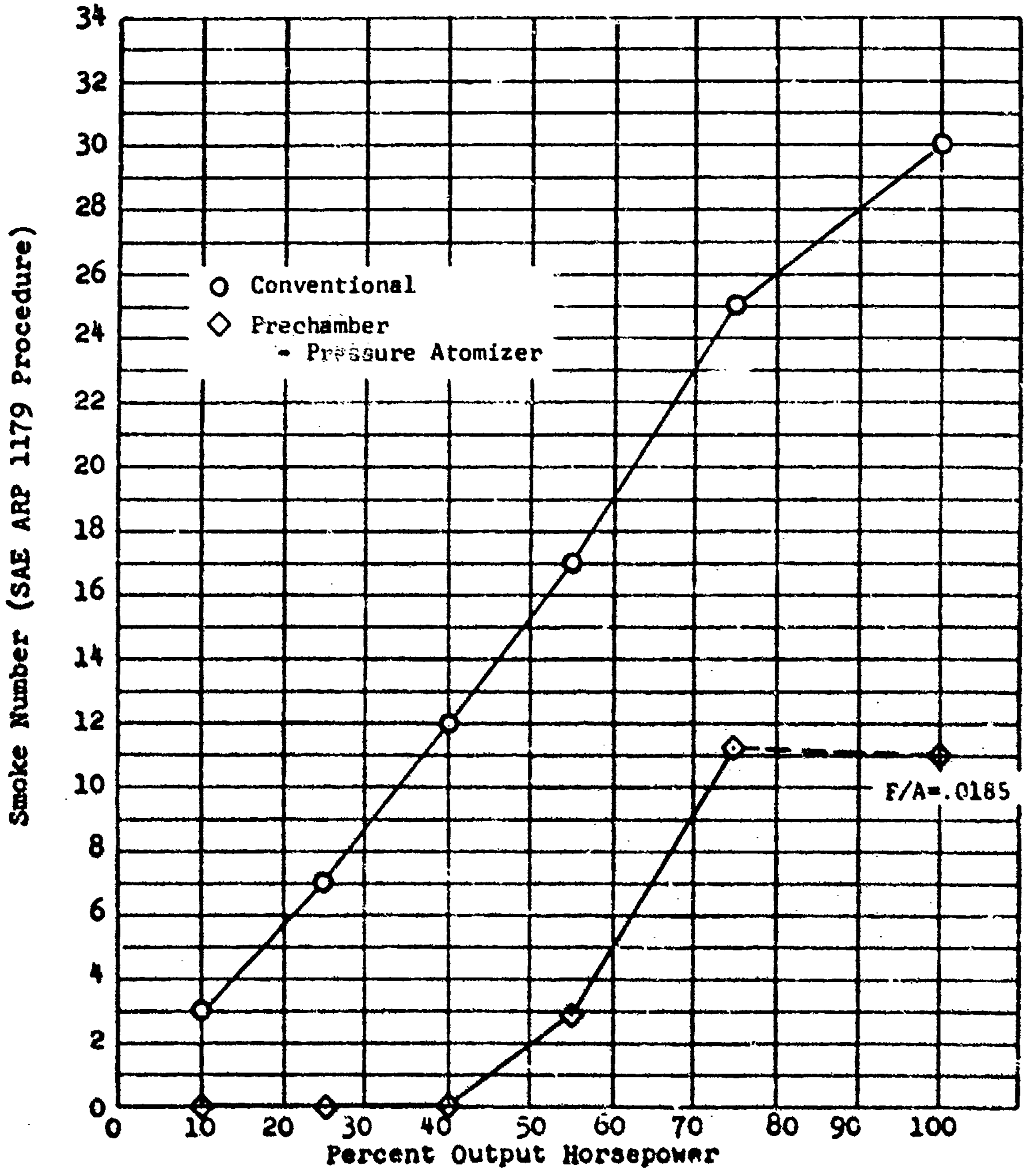

Figure 59. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Final Prechamber Modification "A" Combustor Operating on Pressure-Atomizing Injection And Baseline T63-A-5A Combustor.

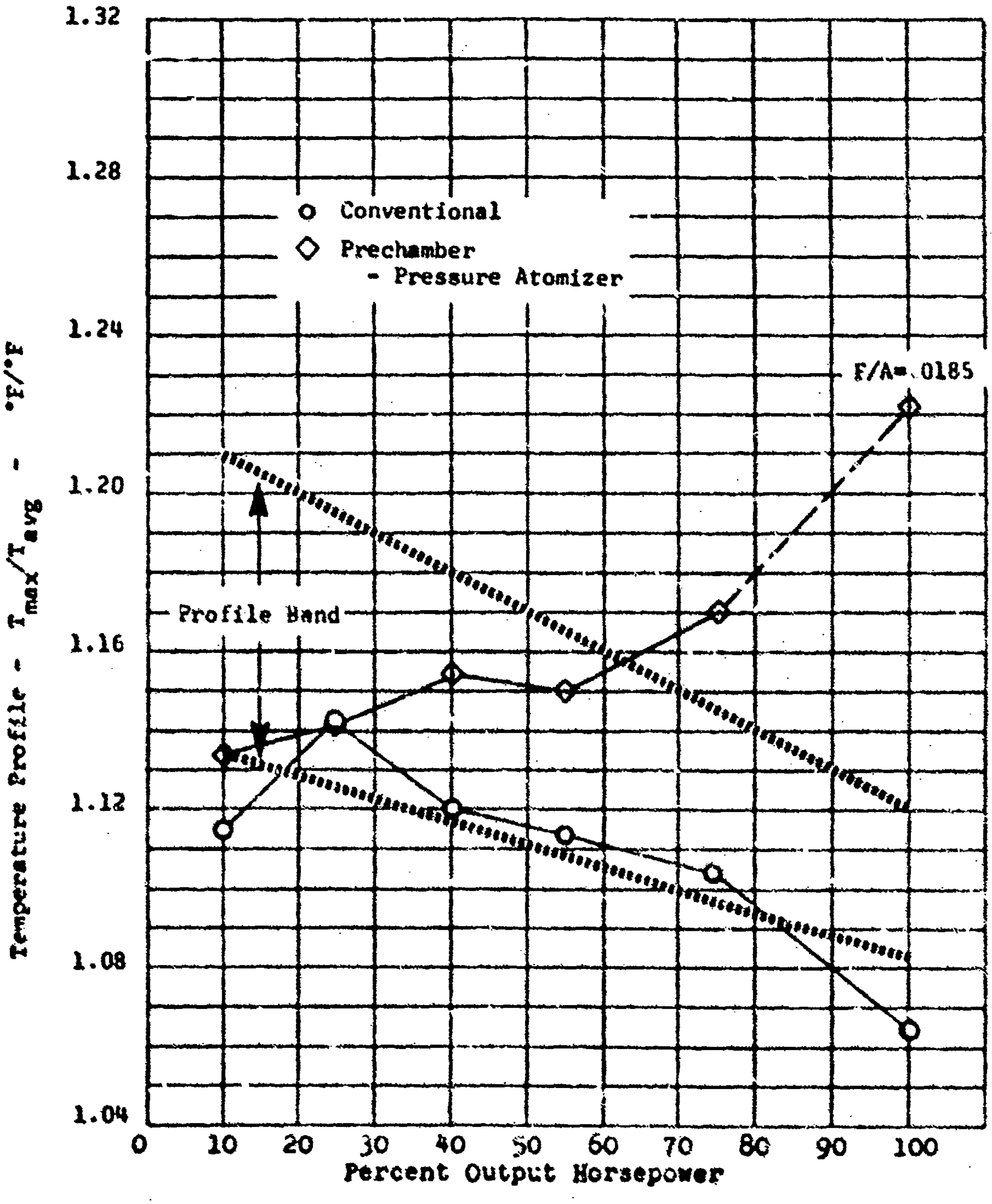

Figure 60. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Final Prechamber Modification "A" Combustor Operating on Pressure-Atomizing Injection And Baseline T63-A-5A Combustor.

TABLE XXXII. FINAL LOW-EMISSION PRECHAMBER COMBUSTOR LINER MODIFICATION "D", OPERATING ON WALL FUEL FILM, NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE

	Cycle Point					
	1	6	5	4	3	2
Emissions						
CO (ppm)	426.5	185.5	129.4	156.7	156.7	NO DATA TAKEN
H/C (ppm)	85.0	15.0	4.4	.7	.2	
NO_x (On-Line, CL) (ppm)	16.7	16.7	25.4	40.0	57.4	
NO_x (On-Line, NDIR & NDUV) (ppm)	13.5	18.1	27.5	39.2	50.9	
NO_x Saltzman (ppm)	12.4	19.2	32.6	38.2	66.5	
Smoke Number	.01	.00	.00	.00	.00	
Pressure Loss (%)	6.14	6.72	6.78	6.67	6.15	
Temp. Profile (T_{max}/T_{avg})	1.361	1.294	1.230	1.230	1.317	

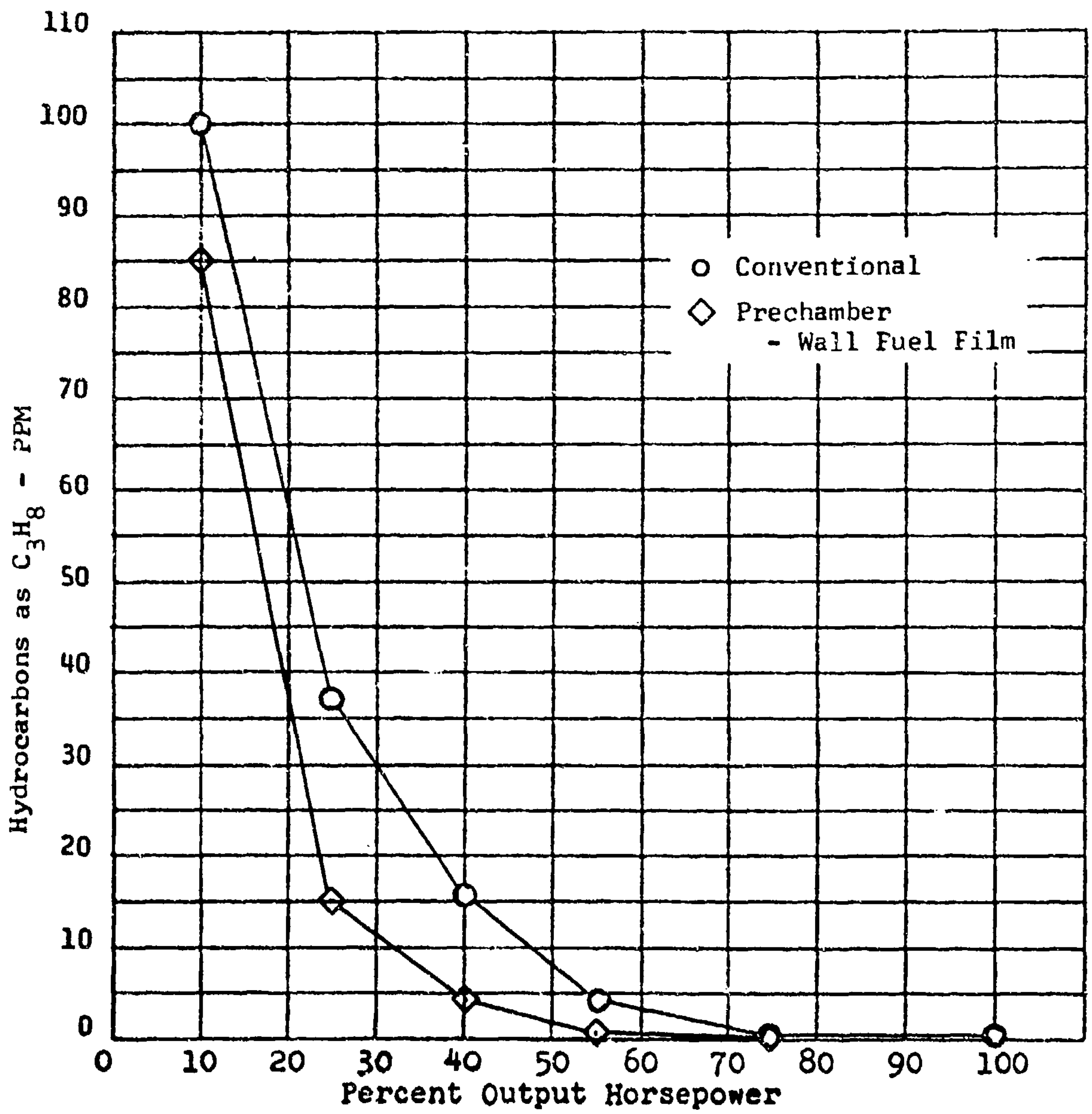

Figure 61. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Final Prechamber Modification "D" Combustor Operating on Wall Fuel Film Injection And Baseline T63-A-5A Combustor.

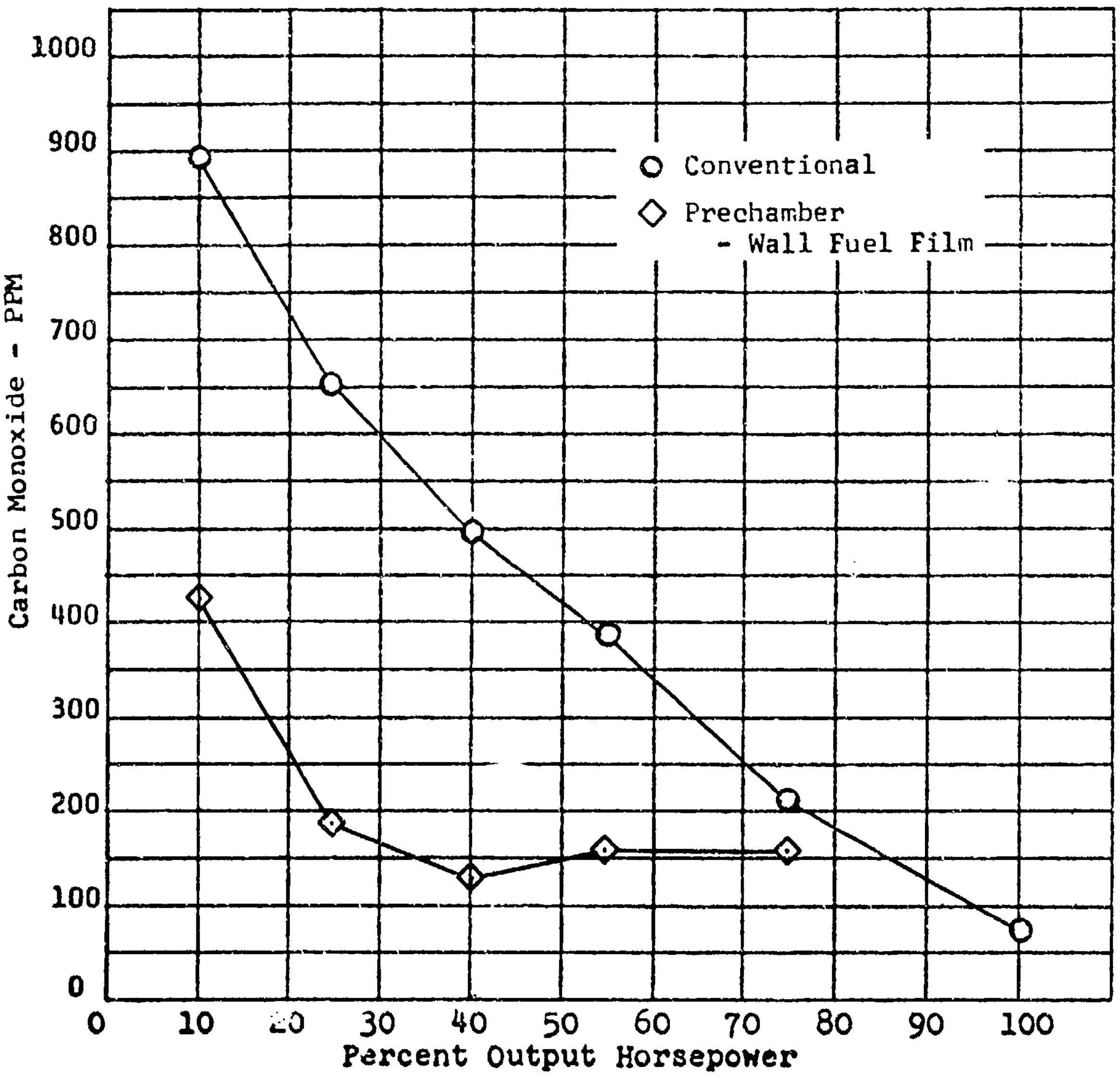

Figure 62. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Final Prechamber Modification "D" Combustor Operating on Wall Fuel Film Injection And Baseline T63-A-5A Combustor.

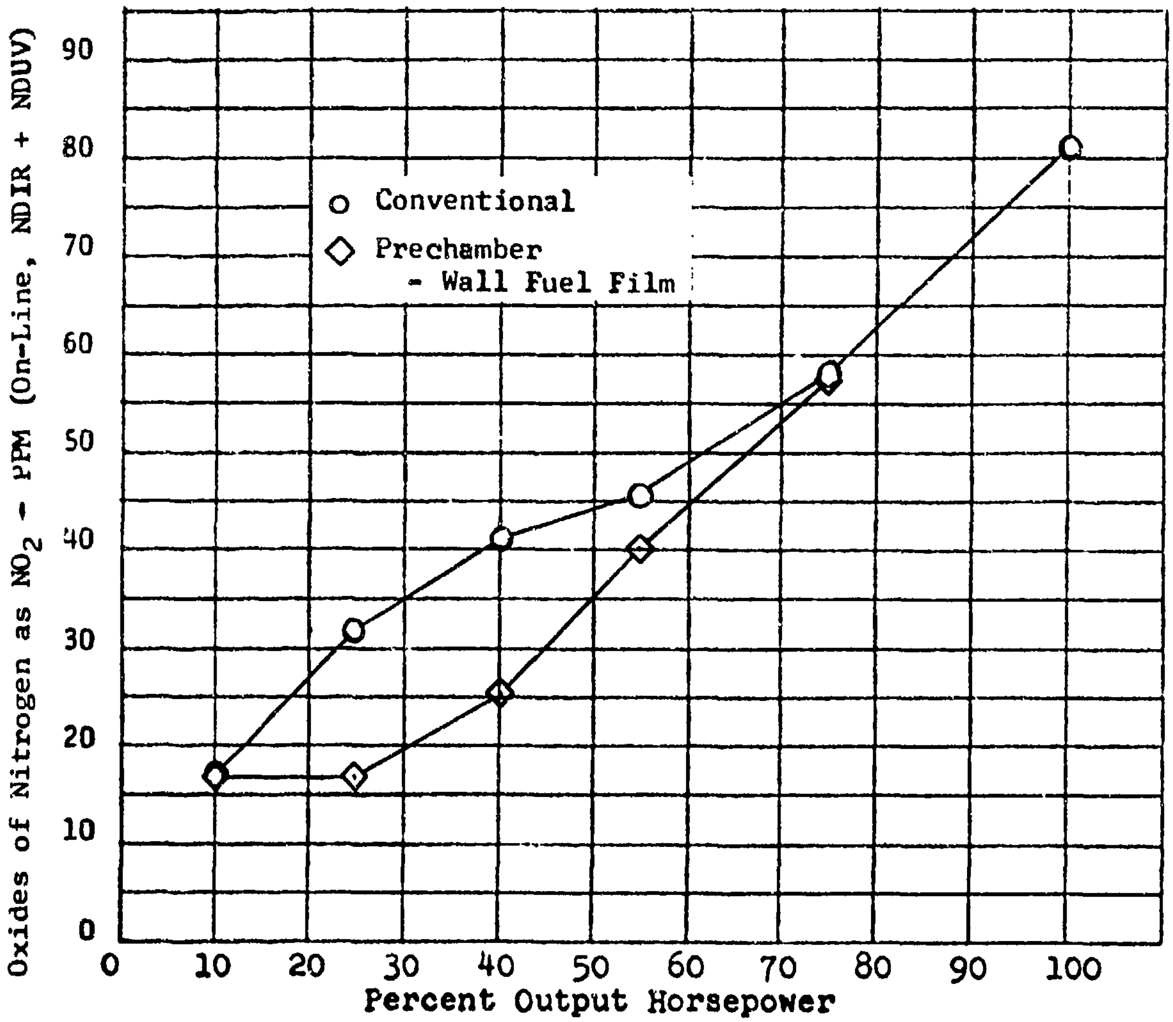

Figure 63. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Final Prechamber Modification "D" Combustor Operating on Wall Fuel Film Injection And Baseline T63-A-5A Combustor.

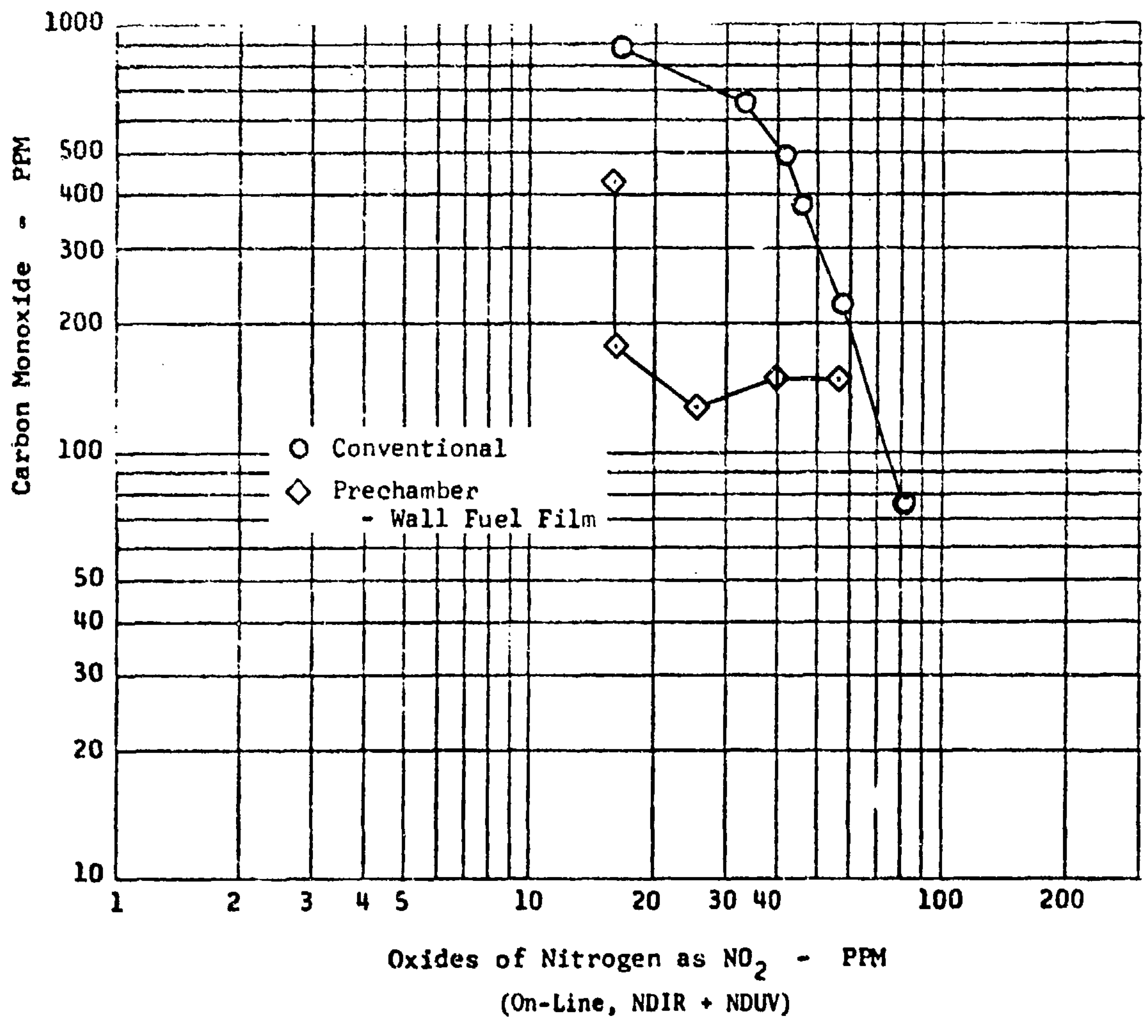

Figure 64. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Final Prechamber Modification "D" Combustor Operating on Wall Fuel Film Injection and Baseline T63-A-5A Combustor.

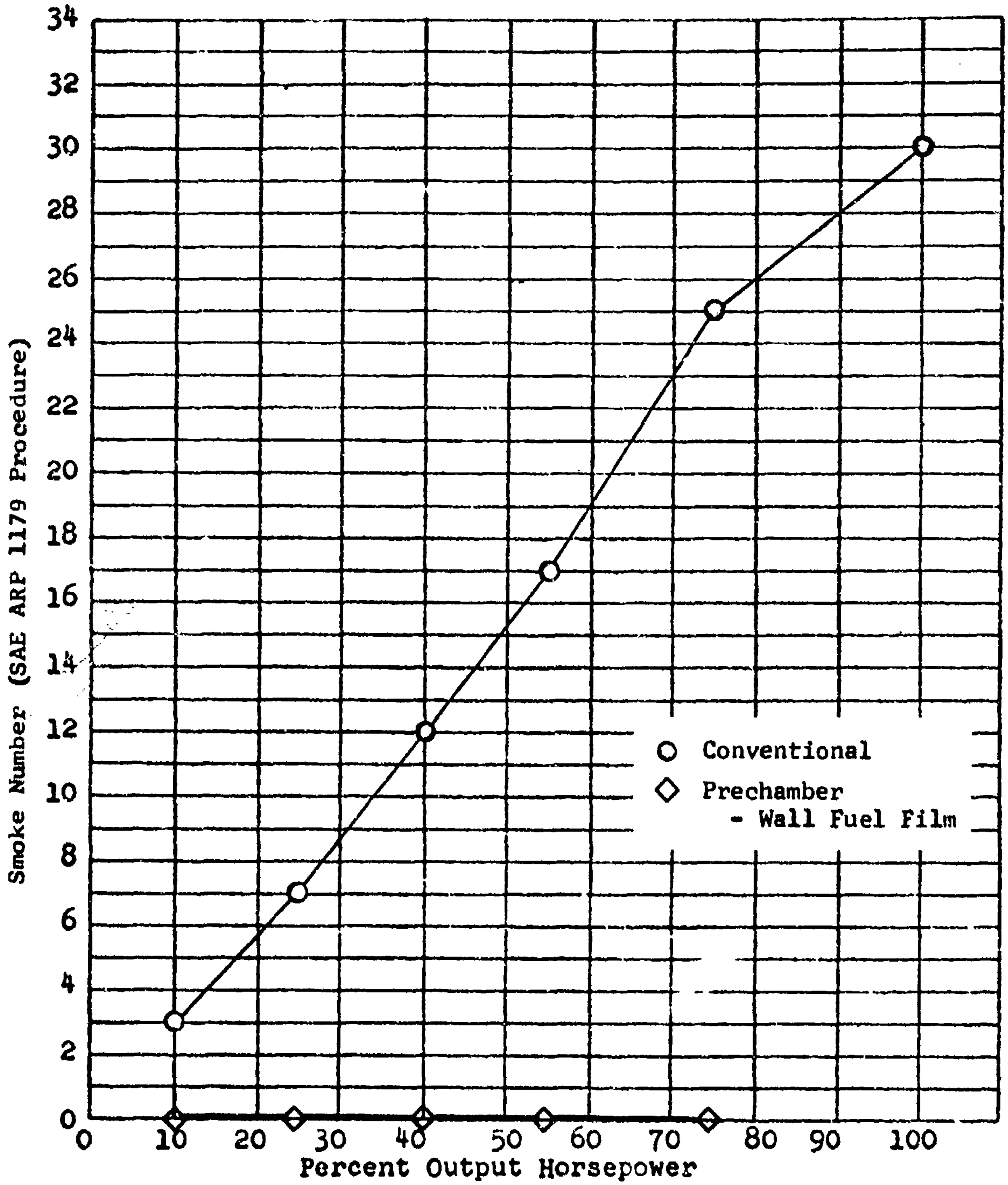

Figure 65. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Final Prechamber Modification "D" Combustor Operating on Wall Fuel Film Injection And Baseline T63-A-5A Combustor.

were zero. This is the only configuration of a Final Prechamber combustor that produced no smoke. Temperature profile, however, remained a significant problem, see Figure 66. In no Final Prechamber configuration did wall fuel film operation produce an exhaust profile comparable to pressure atomizer operation or to the Preliminary Prechamber combustor, which had used wall fuel film injection. The pressure loss for this combustor was approximately 2% higher than the pressure loss in the conventional T63 combustor liner. Part of this increase in loss, about 0.5%, resulted from the increase in flowpath length for the combustor inlet air. The balance of the loss resulted from a combination of the narrow convective cooling annulus, formed between the liner and the combustor outer case, and the closing of the reaction zone holes. Further, development of this combustor must include reducing the pressure loss to the 4.0% to 4.5% level.

Using extrapolated 100% power emission concentrations as was done when no test data were available, the Final Prechamber Modification "D" combustor produced 47% less total emissions than the conventional T63-A-5A combustor over the LOH duty cycle and allowed no increase in any constituent emission. Even though this combustor fell 3% short of the 50% emission reduction goal, its elimination of smoke and reduction of each constituent emission make it the "best" wall-fuel-film Prechamber combustor of the Final Prechamber configurations.

Final Modified Conventional Combustion Liner

Four preliminary low-emission combustor concepts which demonstrated effective emission reductions were incorporated into the Final Modified Conventional Combustor Liner. The Modified Conventional Combustor concept was envisioned as the inclusion of current-technology emission abatement techniques into the basic envelope of the conventional T63-A-5A combustor liner. The axial length of the modified conventional combustor was maintained equal to the conventional combustor; the liner dome, ignition system, primary-zone section, and axial cross-sections remained unchanged. The emission abatement concepts added to the conventional combustor were as follows:

- Convection cooling of the primary zone.
- Delayed dilution.
- Variable dilution geometry.
- Air-blast fuel injection.

The first three of these concepts, when incorporated into the conventional T63-A-5A combustor liner, resulted in the initial design modified conventional combustor liner shown in the photograph in Figure 67. In this design, the variable-geometry dilution band was fabricated for two geometry settings. The "closed" setting was a set of six 1.047 inch-diameter holes which distributed the liner flow splits in the same proportion as the flow splits in the conventional T63 combustor. In this setting, the maximum-power primary-

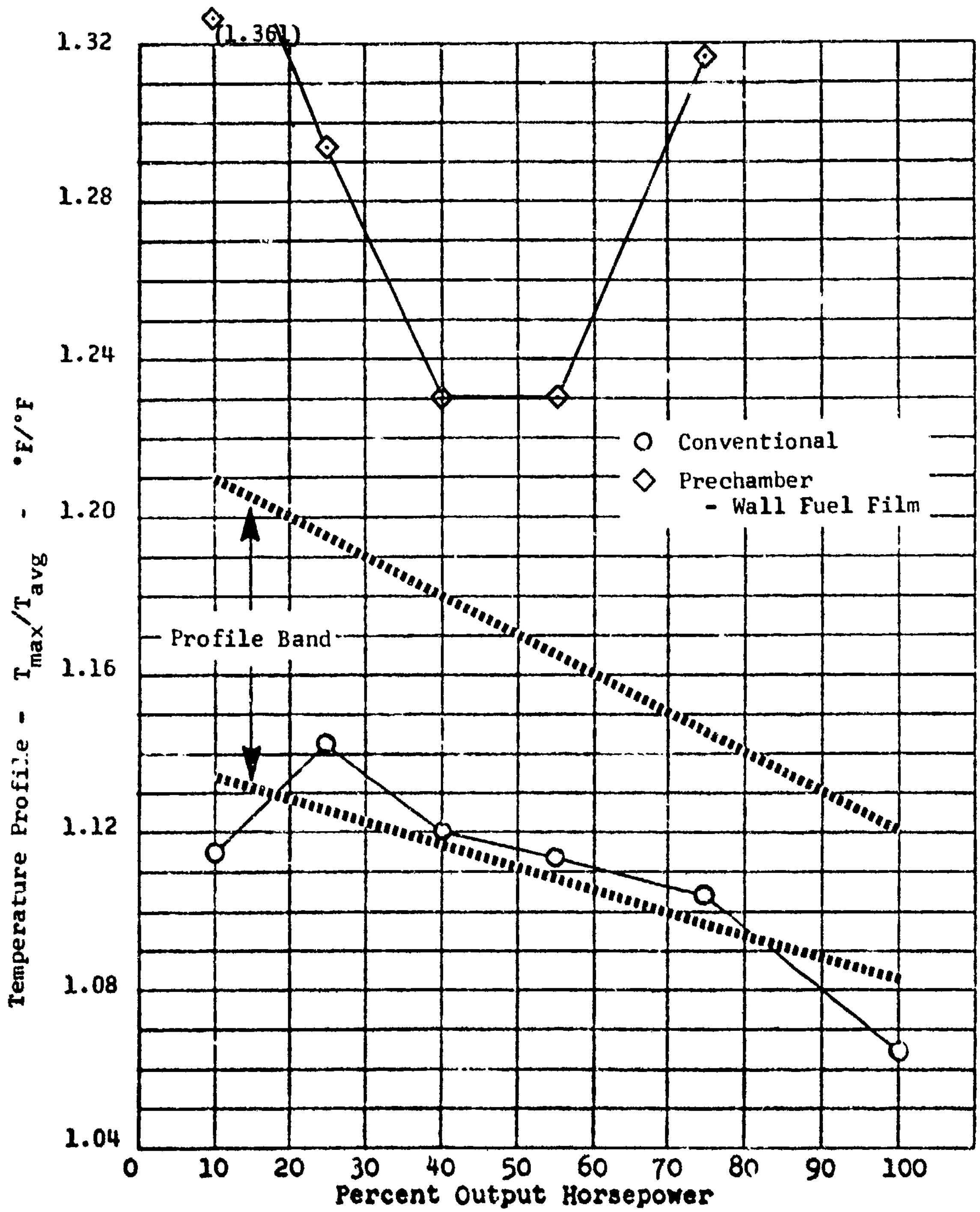

Figure 66. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Final Prechamber Modification "D" Combustor Operating on Wall Fuel Film Injection And Baseline T63-A-5A Combustor.

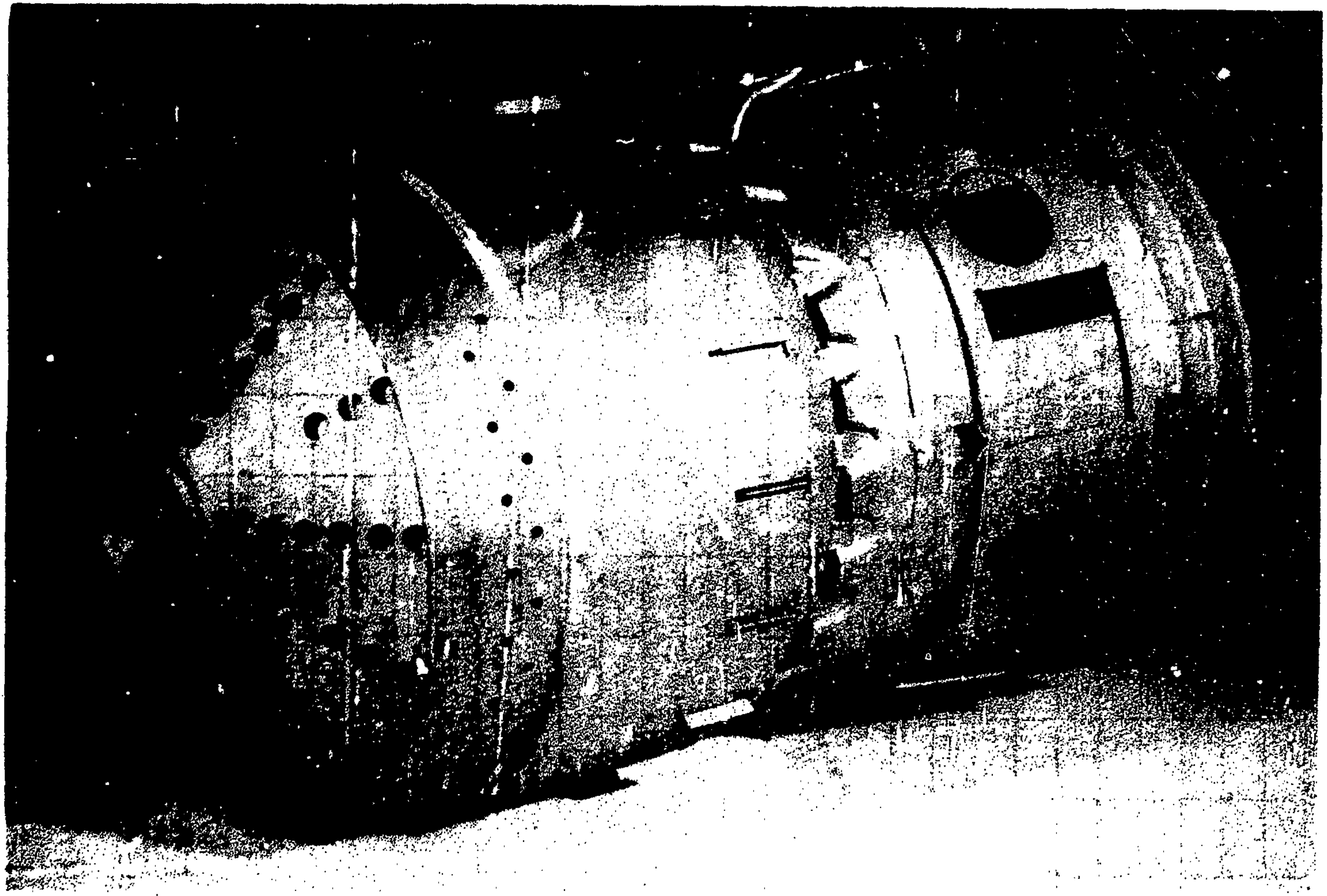

Figure 67. Final Low-Emission Modified Conventional Combustor Liner, Initial Design.

zone equivalence ratio was 0.77, and the emission reductions obtained relied upon the primary-zone convection cooling and the delayed dilution. The second dilution geometry setting injected dilution air through a set of 1.37 inch-square holes. This setting repeated the flow splits in the regenerative T63 combustor and was intended for use at regenerative conditions.

The Modified Conventional Initial Design combustor produced low total emissions, but NO_x and particulates were above the Conventional T63 levels.

In an attempt to reduce the NO_x and particulate emissions, the combustor was reworked into Modification "A" by moving the dilution 2.00 inches upstream and replacing the two sets of dilution holes with a single set. This location, which was the same as that in the Conventional T63-A-5A combustor liner, still retained a degree of delayed dilution as the trim air holes used in the Conventional T63 combustor were combined into the dilution holes. A lack of variable-geometry effectiveness caused by seizing of the dilution slip band plus a low combustor pressure loss produced poor combustor performance.

Modification "B" of the Final Modified Conventional combustor liner was the refining of the concepts in Modification "A" plus the change from a standard T63 pressure atomizing fuel injector to an air-blast pressure atomizing fuel injector, which had been evaluated in the preliminary low-emission combustor concept tests. In addition to the fuel injector change, the dilution variable-geometry section was replaced with the new hardware, which improved the mechanical operation of the slip band and strengthened the actuator tabs. To increase the pressure loss and improve mixing and recirculation, the primary zone and dilution zone holes were reduced. The primary zone holes were reduced from 0.610 inch diameter to 0.500 inch diameter, and the dilution holes were reduced from six 1.22 inch-square holes with 0.41 inch-radius curves to four 1.22 inch by 1.41 inch holes with 0.41 inch-radius curves. The four dilution holes were fabricated on a basis of six holes; thus each pair of holes was adjacent to the inlet air from the two engine feed arms. A photograph of the exterior of the Modified Conventional Modification "B" combustor liner is presented in Figure 68, and an internal view is shown in Figure 69.

The mechanical operation of the Modification "B" variable dilution geometry slip band proved to be quite satisfactory, and four different geometry settings were used during the rig testing: 0%, 28%, 50%, and 71% closed. The 28% closed setting corresponded to the "nonregenerative" setting, duplicating the Conventional T63 combustor flow splits. The 0% closed setting corresponded to the "regenerative" liner flow splits.

Modification "B" was the final configuration in the Final Modified Conventional combustor liner series on this contract. With

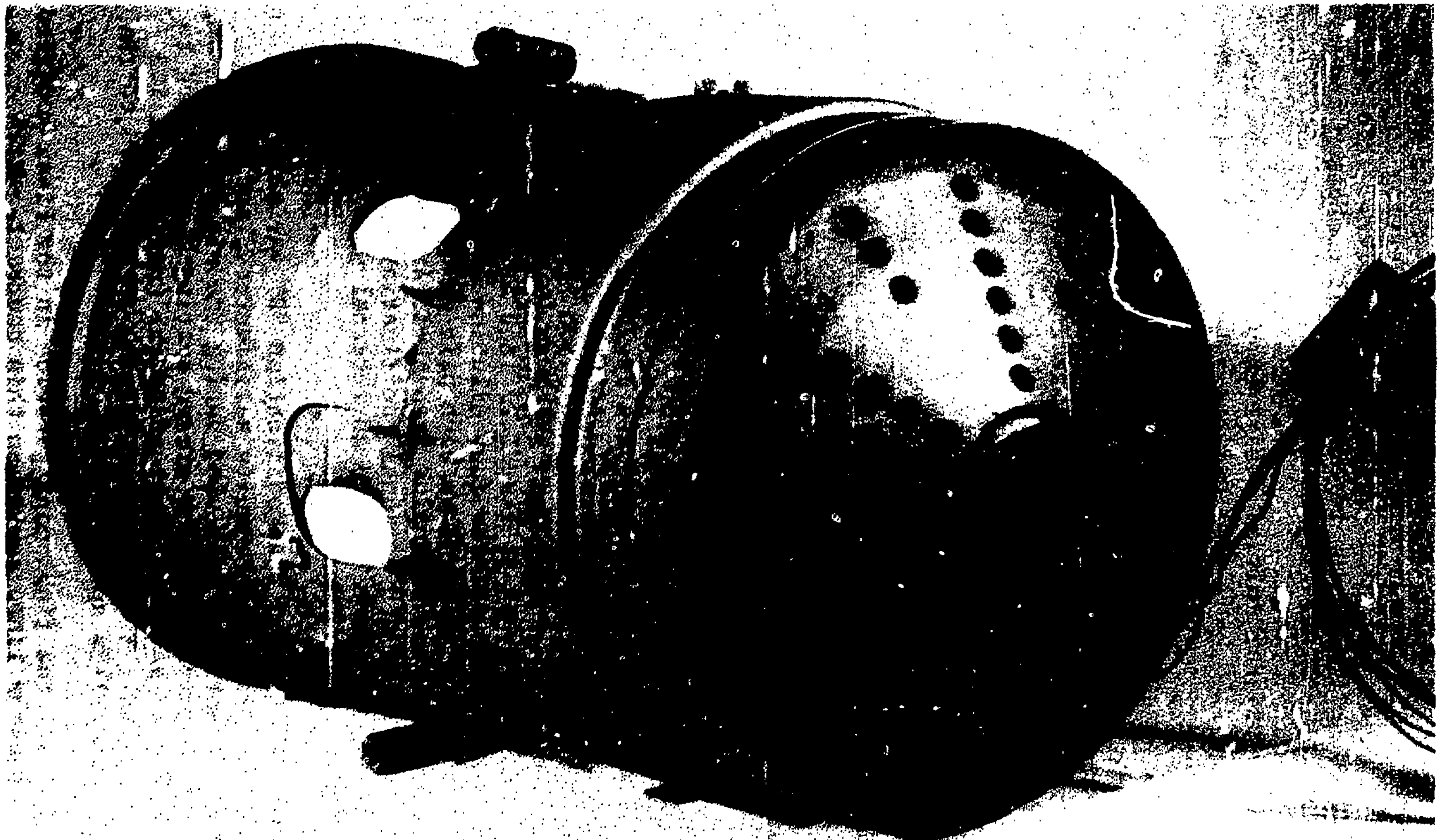

Figure 68. Final Low-Emission Modified Conventional Combustor Liner, Modification "B", External View.

Figure 69. Final Low-Emission Modified Conventional Combustor Liner, Modification "B", Internal View.

two dilution geometry settings, 28% closed at low-power conditions and 50% closed at the high-power conditions, Modification "B" reduced total emissions 51% over the LOH duty cycle when compared to the Conventional T63-A-5A combustor emissions. All constituent emissions were reduced except particulates, which were 25% above the Conventional T63 baseline levels. Compared to the particulates measured from a Conventional T63 combustor in the second baseline retest, the Modified Conventional Modification "B" combustor particulates were 73% lower.

Emissions and combustor performance data for all three modifications of the Final Modified Conventional combustor liner were recorded at various dilution geometry settings and each of the six T63 nonregenerative operating conditions. In addition to the automatic data acquisition instrumentation read for each low-emission combustor tested, three skin thermocouples were attached to the Modified Conventional combustors at different primary zone axial locations. Temperatures from these thermocouples were manually recorded at each data point for the initial design and Modification "A". Mechanical failure of the thermocouple leads inside the convection cooling shell prevented the acquisition of any skin temperatures from the Modification "B" testing.

The following paragraphs present the test results from the "best" Final Modified Conventional combustor liner — Modification "B". The test results from the Initial Design and Modification "A" liner testing are documented in Appendix IV, along with additional details from the Modification "B" testing.

The design changes to the Final Modified Conventional combustor which resulted in Modification "B" were the following:

- A new variable-geometry slip band was fabricated which would operate more smoothly and would have lower leakage.
- The cantelevered actuator tabs connecting the actuator rods to the slip band were redesigned to increase their stiffness and to eliminate any deformation during testing.
- The primary holes and dilution holes were reduced in area to increas the combustor pressure loss from 3% to 5% at the design setting.
- The dilution hole pattern was changed from six holes equally spaced to four holes spaced in a six-hole pattern.
- In order to reduce the smoke and particulates, an Ex-Cell-O air-blast pressure atomizing fuel injector was installed.

Modification "B" of the Final Modified Conventional combustor liner was tested at three different geometry settings over the nonregenerative operating conditions. The settings were 0%, 28%, and 50% closed. The 28% closed setting was the nominal design point for the nonregenerative tests. The regenerative position was intended to be 0% closed or full open.

Two of the skin thermocouple leads were broken prior to the rig tests of Modification "B"; no skin temperature data were recorded for this configuration. Pressure loss results from the nonregenerative tests are summarized in Table XXXIII. On the average, the pressure losses for 0%, 28%, and 50% closed dilution settings were 4%, 5%, and 7%. The mechanical operation of the combustor variable dilution geometry gave no problems during the test. With the dilution geometry set at the 28% closed position, combustion lean blowout from idle T63 nonregenerative combustor conditions was obtained at a fuel/air ratio of 0.0042.

The measured exhaust emissions are summarized in Table XXXIV. Comparisons of these emissions with the Conventional T63 combustor liner appear in Figures 70 through 74. The settings which resulted in the lowest LOH duty cycle total emissions are shown for the Modified Conventional combustor liner. The hydrocarbon emissions are shown in Figure 70. A significant reduction in hydrocarbon emissions was obtained in closing the dilution holes from 0% to 28% closed. Further restriction of the dilution resulted in only a minor additional reduction. Overall, hydrocarbon mass emissions were reduced 76% below the Conventional combustor level.

The carbon monoxide concentrations in Figure 71 show that the minimum levels for the Modification "B" combustor were obtained with the 28% closed dilution geometry setting up through the 55% power conditions. At 75% and 100% power, the 50% closed setting gave lowest CO. Over the duty cycle, the Modification "B" combustor reduced carbon monoxide 56%. As can be seen in Figure 72, nitrogen oxide concentrations for both 28% and 50% closed settings were quite similar and well below the conventional combustor level. Modification "B" reduced NO_x by 20% over the duty cycle. The CO vs NO_x tradeoff curves in Figure 73 illustrate that both CO and NO_x concentrations had been reduced. A decrease in one emission was not obtained by simply changing the combustor operating conditions to increase the other constituent.

The greatest effect of changes in dilution geometry was obtained in the smoke number readings; see Figure 74. Even though the air-blast fuel injector greatly reduced the smoke over the LOH duty cycle, particulates were increased by 25% when compared to the original Conventional T63-A-5A baseline smoke measurements.

TABLE XXXIII. COMPARISON OF COMBUSTOR PRESSURE LOSS (%) FOR FINAL DESIGN MODIFIED CONVENTIONAL MODIFICATION "B" COMBUSTOR LINER AND BASELINE COMBUSTORS AT NON-REGENERATIVE OPERATING CONDITIONS.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional T63-A-5A Liner	4.63	4.51	4.53	4.44	4.38	4.14
II. Extended-Length Liner	5.10	4.61	5.09	4.91	4.74	4.59
III. Final Design Modified Conventional Liner Modification "B"						
0% Closed	4.03		3.95			
28% Closed	5.21	4.90	5.18	4.97	4.53	
50% Closed	7.00	6.69	7.08	6.87	6.56	6.01

TABLE XXXIV. EMISSION DATA OF FINAL DESIGN MODIFIED CONVENTIONAL COMBUSTOR LINER MODIFICATION "B" OPERATING AT T63 NONREGENERATIVE COMBUSTOR CONDITIONS

Dilution Zone Variable Geometry Setting	Cycle Point 1	6	5	4	3	2
0% Closed						
CO, ppm	397.0		183.4			
C_xH_y, ppm	35.0		2.2			
NO_x, ppm (NDIR & NDUV)	19.3		36.6			
NO_x, ppm (CL)	9.0		29.5			
NO_x, ppm (Saltzman)	20.2		43.0			
Smoke Index	22.8		36.4			
28% Closed						
CO, ppm	400.6	216.4	166.8	154.7	154.7	
C_xH_y, ppm	20.0	5.0	2.3	2.2	.8	
NO_x, ppm (NDIR & NDUV)	18.0	22.6	27.9	38.4	42.4	
NO_x, ppm (CL)	21.6	17.6	23.6	29.5	36.3	
NO_x, ppm (Saltzman)	20.8	28.2	32.4	40.2	53.8	
Smoke Index	13.0	13.6	14.3	24.2	38.1	
50% Closed						
CO, ppm	717.8	365.9	262.7	181.3	131.3	97.4
C_xH_y, ppm	15.2	4.2	2.8	1.7	.2	.2
NO_x, ppm (NDIR & NDUV)	17.9	19.3	30.0	35.1	44.0	65.1
NO_x, ppm (CL)	8.7	15.8	22.3	29.5	39.2	63.7
NO_x, ppm (Saltzman)	19.2	24.6	31.2	42.1	52.5	75.9
Smoke Index	1.5	4.3	4.3	10.2	19.8	31.0

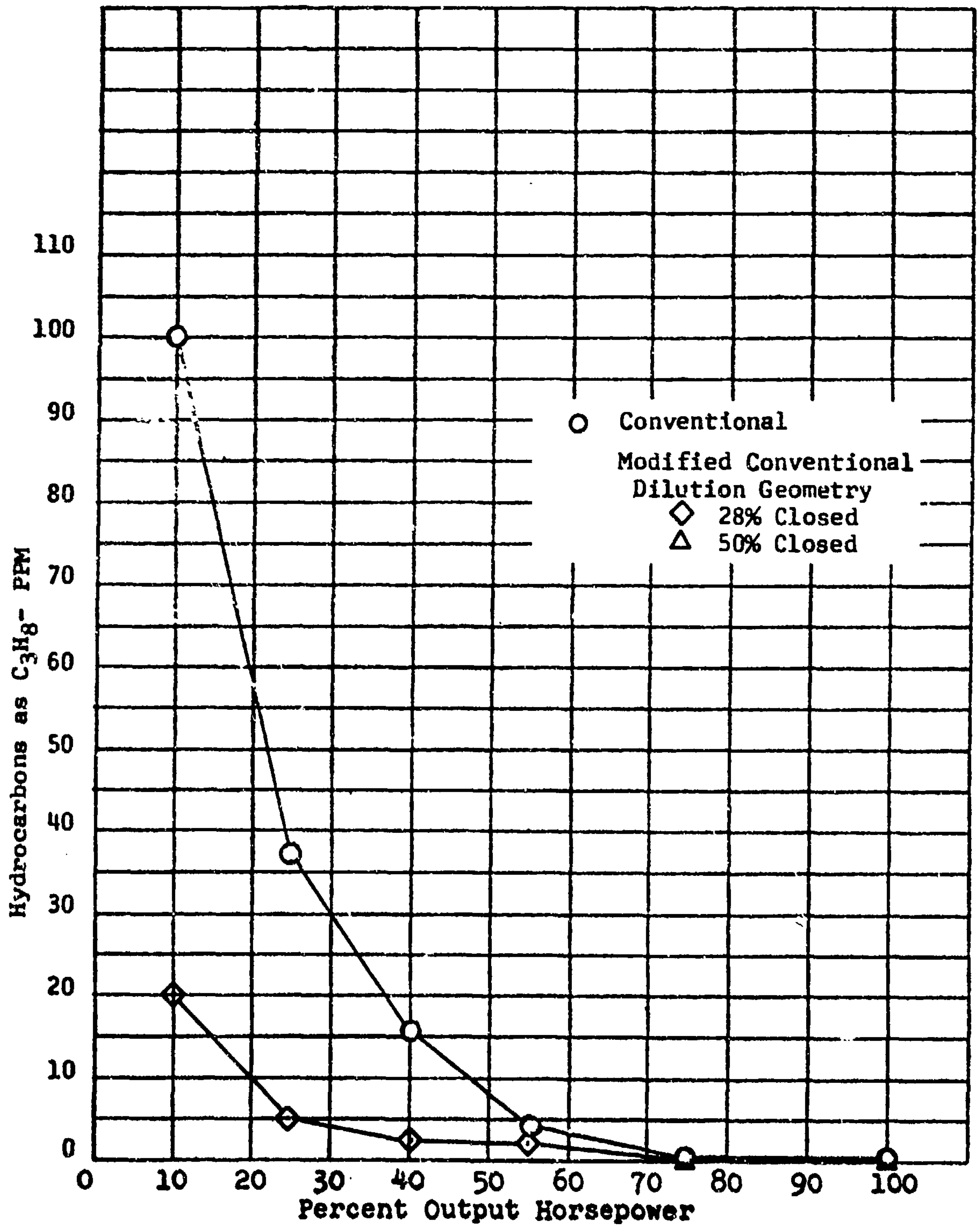

Figure 70. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Final Modified Conventional Modification "B" Combustor at Selected Dilution Geometry Settings and Baseline T63-A-5A Combustor.

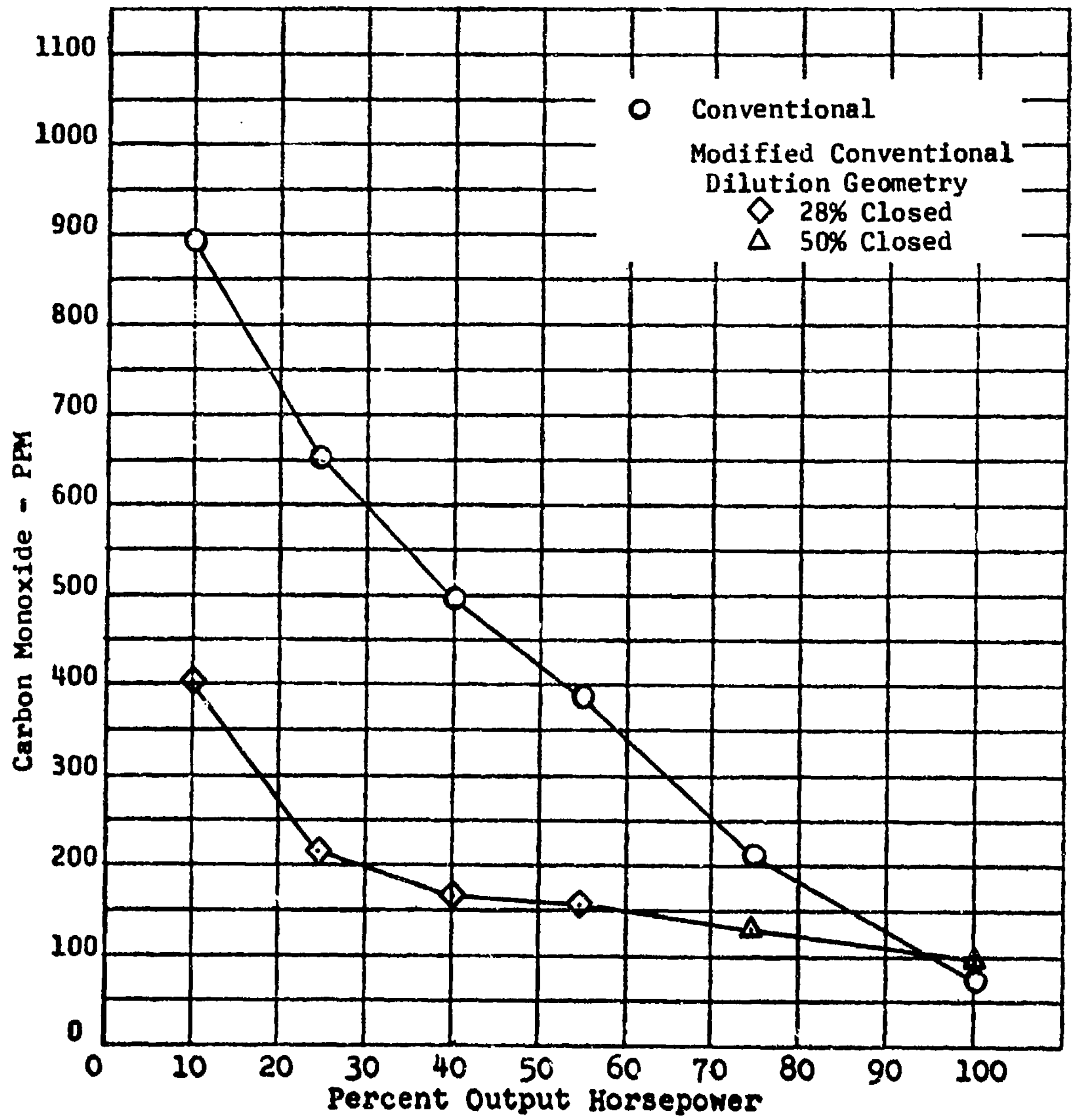

Figure 71. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Final Modified Conventional Modification "B" Combustor at Selected Dilution Geometry Settings and Baseline T63-A-5A Combustor.

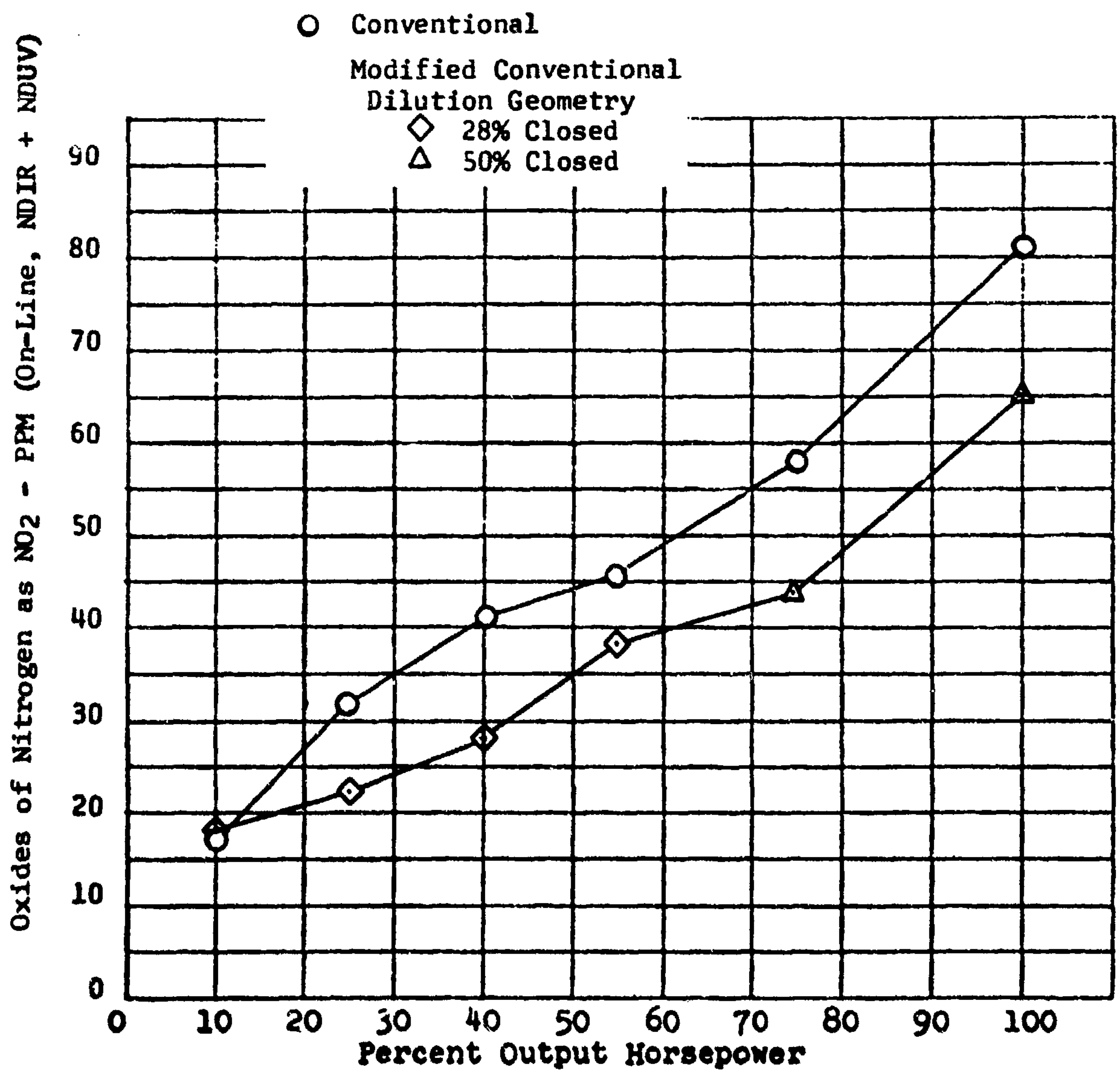

Figure 72. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Final Modified Conventional Modification "B" Combustor at Selected Dilution Geometry Settings and Baseline T63-A-5A Combustor.

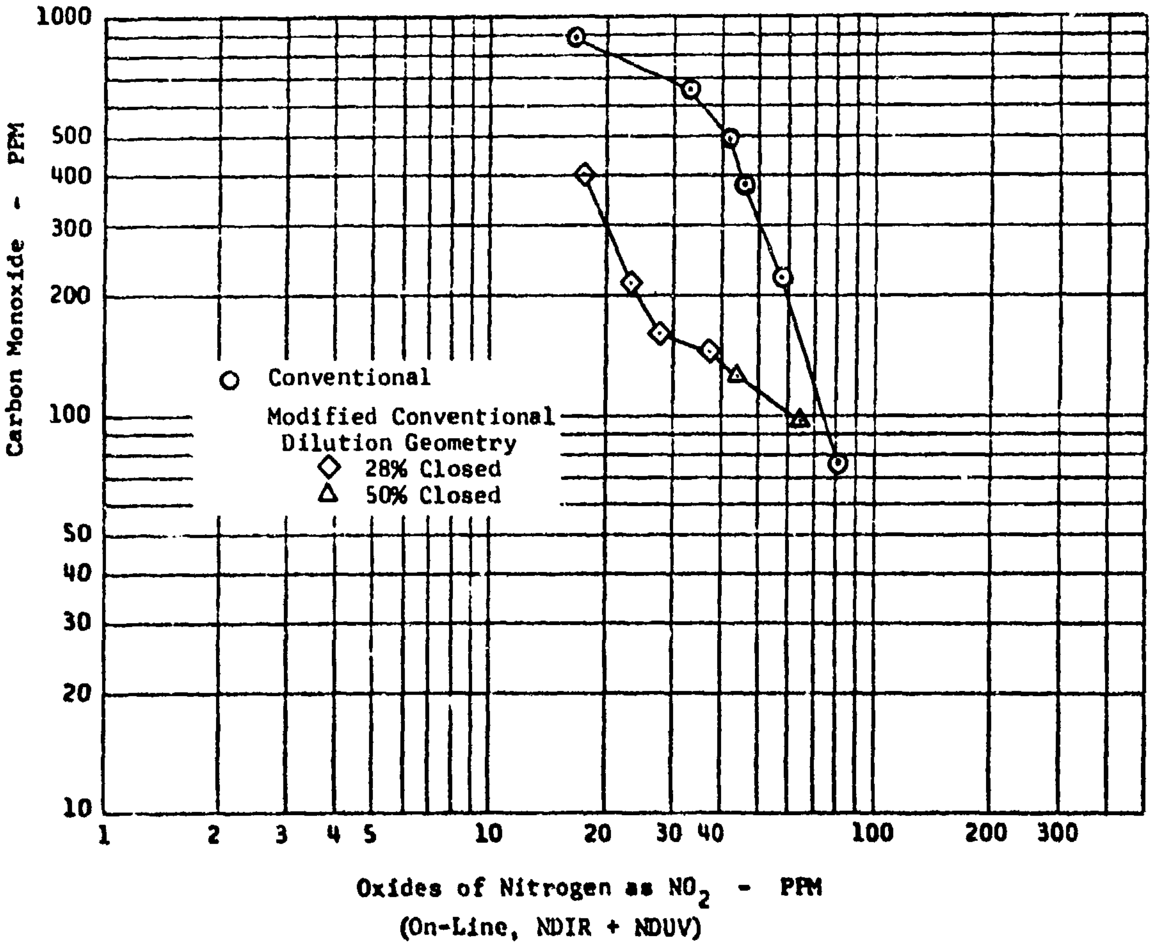

Figure 73. Nonregenerative T63-A-5A Combustor Carbon Monoxide Vs Nitrogen Oxides Emission Data Comparison for Final Modified Conventional Modification "B" Combustor at Selected Dilution Geometry Settings and Baseline T63-A-5A Combustor.

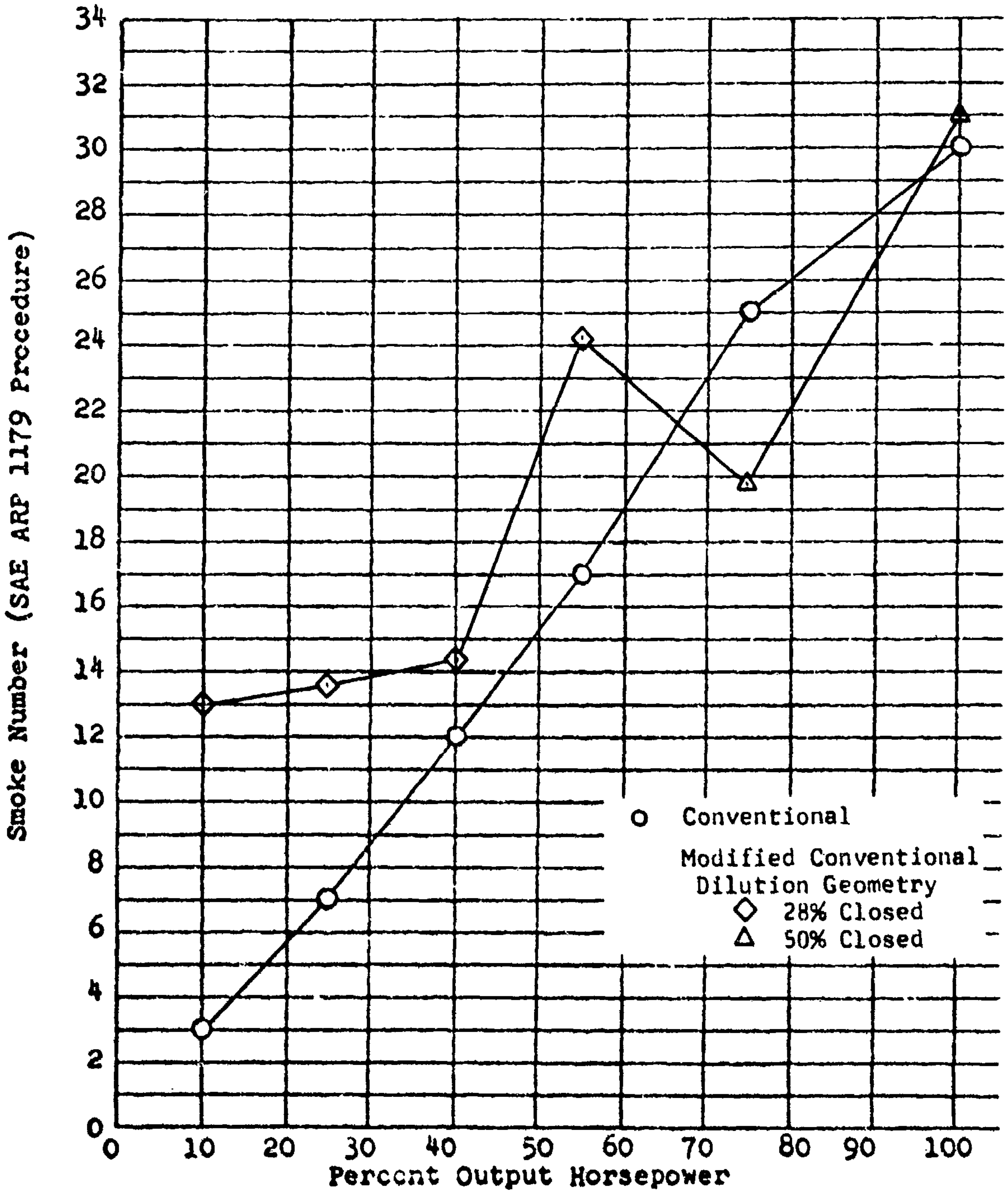

Figure 74. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Final Modified Conventional Modification "B" Combustor at Selected Dilution Geometry Settings and Baseline T63-A-5A Combustor.

When compared to the second baseline retest smoke measurements, the Modification "B" Final Modified Conventional reduced the smoke/particulates by 73%.

The total mass emissions for the Final Design Modified Conventional Modification "B" combustor liner was 51% below the total emissions from the Conventional T63-A-5A combustor liner. A summary of the emission performance for each configuration of the Modified Conventional combustor liner is given in Table XXXV. Even though Modification "B" did not produce the total reduction of the initial design, it was able to reduce hydrocarbons, carbon monoxide, and nitrogen oxide simultaneously.

The exhaust temperature profiles for the Conventional T63 combustor liner and the Final Modified Conventional Modification "B" combustor liner are compared in Table XXXVI and Figure 75. The temperature profile for the 50% closed geometry setting was the best of the Final Combustors tested. Even at maximum power conditions, the worst profile measured for the 50% closed setting, the T_{max}/T_{avg} value was only 1.145. Additional development is required on the Modified Conventional combustor to improve the exhaust temperature profile over the variable geometry schedule which produces the lowest emissions.

Emission response of the Modified Conventional combustor to changes in variable geometry setting was not as sensitive as indicated by the reaction kinetics and empirical correlation predictions. The probable reason for the reduced effectiveness of the variable geometry was the fuel droplet burning from the pressure atomizing fuel injectors. The fuel rich regions surrounding each fuel droplet were locally little affected by the changes in primary mass flow; the flame temperatures were also little affected. Changes in pressure loss with variable geometry setting had an effect on fuel droplet size and distribution for the air-blast fuel injector. Primary-zone mixing is not sufficient with pressure atomized or air-blast fuel injection systems to permit a uniform change in primary-zone fuel/air ratio. The ineffectiveness on NO_x control was especially evident, which supports the contention that droplet burning negates much of the variable geometry control on the burning mechanism. If variable geometry were combined with a premixed-prevaporized fuel preparation system in a combustor, the emissions response should greatly improve. A properly designed premixed-prevaporized combustor would produce a homogeneous primary zone and thus the theoretical primary zone fuel/air response should be reflected in the flame temperature and thus in the exhaust emissions. The Prechamber combustor, since it has a premixed-prevaporized fuel preparation system, should respond better to variable geometry than the Modified Conventional combustor.

TABLE XXXV. EMISSION INDEX SUMMARY FOR T63 BASELINE AND FINAL MODIFIED CONVENTIONAL COMBUSTORS

Combustor Tested	C_xH_y	CO	NO_x	Particu-lates	Total Emissions
EMISSION INDEX (lb /1000 lb fuel)					
• Baseline	1.544	26.094	5.068	.239	32.945
• Final Modified Conventional					
Initial Design	.161	6.878	5.970	.438	13.447
Modification "A"	.500	15.966	4.499	3.471	24.436
Modification "B"	.364	11.432	4.068	.298	16.162
RELATIVE EMISSION INDEX (%)					
• Baseline	100	100	100	100	100
• Final Modified Conventional					
Initial Design	10	26	118	183	41
Modification "A"	32	61	87	1452	74
Modification "B"	24	44	80	125	49

TABLE XXXVI. COMPARISON OF EXHAUST TEMPERATURE PROFILE (T_{max}/T_{avg}) OF FINAL DESIGN MODIFIED CONVENTIONAL COMBUSTOR LINER MODIFICATION "B" AND BASELINE COMBUSTOR LINERS AT T63 NON-REGENERATIVE CONDITIONS.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional T63-A-5A Liner	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner	1.229	1.210	1.198	1.171	1.129	1.188
III. Final Design Modified Conventional Liner Modification "B"						
0% Closed	1.224		1.154			
28% Closed	1.192	1.231	1.268	1.295	1.318	
50% Closed	1.127	1.131	1.115	1.128	1.139	1.145

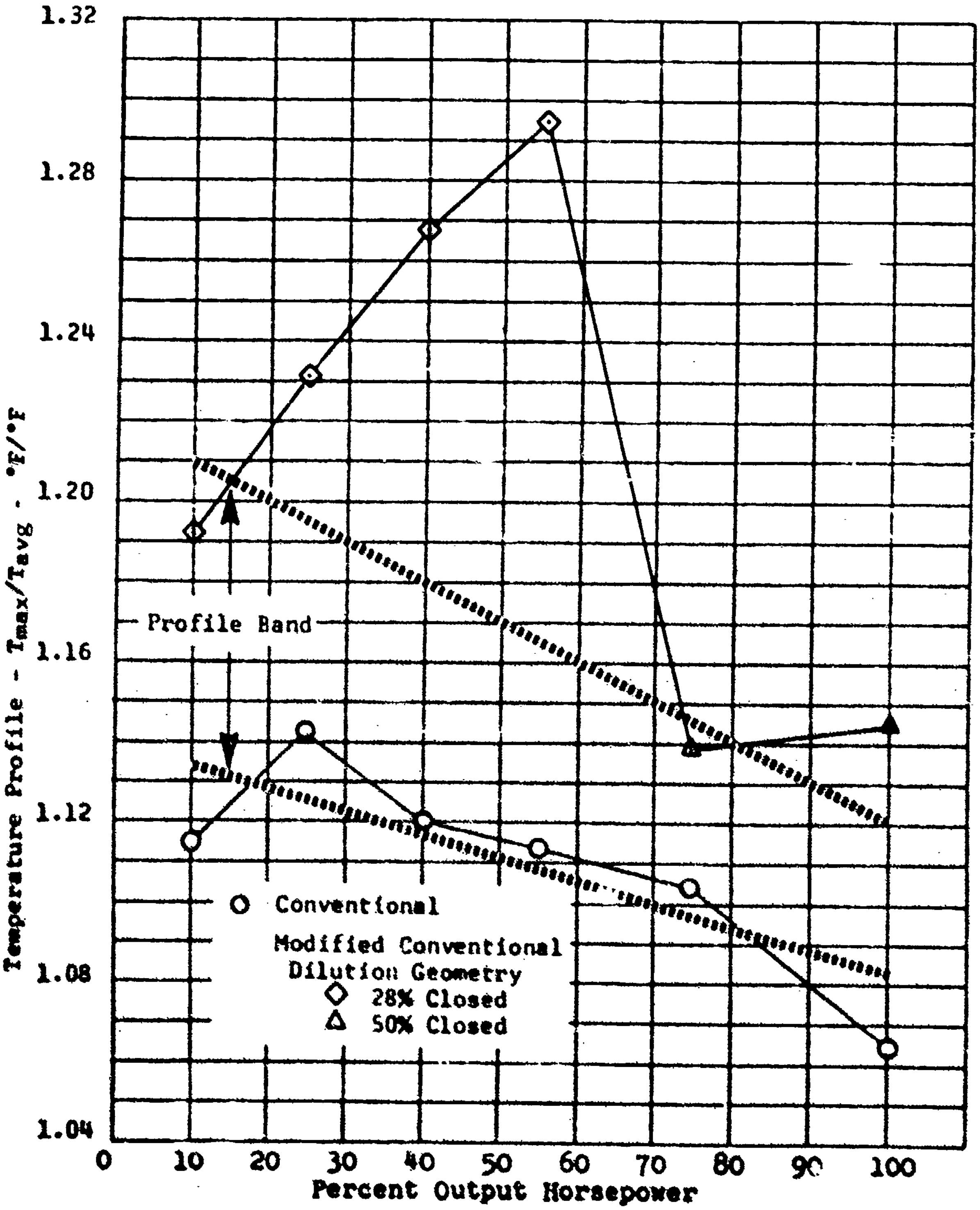

Figure 75. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Final Modified Conventional Modification "B" Combustor at Selected Dilution Geometry Settings and Baseline T63-A-5A Combustor.

CONCLUSIONS

The significant conclusions resulting from the analytical and experimental combustor investigations are summarized in the following sections.

TASK 1 - PROBLEM DEFINITION

1. The Army light observation helicopter (LOH) duty cycle selected for this study reflected the large percentage of time these aircraft spend at cruise, climb/hover, and descent power levels. Idle and takeoff account for only 20% of the time that these aircraft are being operated.

2. It was found that the effectiveness of combustor variable geometry is significantly influenced by the power level-time distribution of the duty cycle used. Since variable geometry is used to control the reaction zone conditions, it is most effective for emissions tradeoffs between substantially different power level conditions.

3. Carbon monoxide accounted for 78% of the mass emissions produced by a conventional T63-A-5A engine over the LOH duty cycle. Nitrogen oxides accounted for 12.5% of the total mass emissions. Thus, to attain a 50% or more reduction in total emissions, the carbon monoxide emissions had to be decreased more than 50% while allowing no other constituents to increase.

TASK 2 - CONCEPT ANALYSIS AND SELECTION

1. The validity of using reaction kinetics for predicting the emission trends in combustors was upheld by experimental testing.

2. The published test data used in the analysis of potential low-emission combustor concepts were in general found to be inadequately documented. It is known that many low-emission approaches only trade off a decrease in one constituent, such as NO_x, for an increase in another, such as CO. Often only one constituent was documented in the literature with no indication as to the effect on other constituents. This led to the selection of some very poor preliminary concepts for experimental testing.

TASK 3 - TEST

The conclusions resulting from the experimental testing of combustors are grouped into the three general types of combustors tested: baseline combustors, preliminary low-emission combustors, and final low-emission combustors.

Baseline Combustors

1. The concentrations of exhaust emissions measured in the T63 engine agreed favorably with the concentrations measured in the combustor test rig.

2. Combustor inlet air moisture levels appeared to have some effect on the NO_x emissions, no effect on CO and C_xH_y emissions, and apparently a significant effect on smoke or particulate generation. Although other, unknown factors may have been the cause of the smoke variation, the effect of moisture or humidity on exhaust emissions was found to be a significant problem area.

Preliminary Low-Emission Combustors

1. Minor changes in conventional combustor geometry can significantly affect emissions. The effects were predicted in Task 2 and verified in the Task 3 tests. One simple change was the moving of the dilution holes aft, which resulted in the reduction of total emissions by 38% with no increase in any emission constituent. Changes such as this and others discussed herein could be applied to conventional combustor design practices to reduce pollution.

2. Other low-emission approaches investigated in the preliminary evaluations involved new combustor concepts. These concepts can be categorized into two approaches:

   a. Premix/Prevaporization

   b. Massive Primary-Zone Recirculation/Plug Flow.

It was demonstrated that these approaches have the potential of reducing emissions much further than simply modifying the combustor. Longer development time will be required to develop the technology to apply these concepts.

Final Low-Emission Combustors

1. Three versions of two combustor concepts generally met the contract objectives of emission reduction. The Final Modified Conventional Combustor reduced emissions by 51%. The Final Prechamber combustor reduced total emissions 55% when operating on a pressure atomizing fuel injection system and 47% when operating on wall fuel film injection.

2. The final combustor designs were not designed for light weight but still did not result in excessive combustor weights. A production T63-A-5A combustor liner weighs 1.75 lb. The Final Prechamber combustor weighed 3.08 lb (76% heavier than the T63 combustor), and the Final Modified Conventional combustor weighed 3.48 lb (99% heavier than the conventional combustor).

3. In general, the final combustors met the combustor performance contract objectives. Pressure loss, stability, durability, and lightoff/relight capability were shown. Exhaust temperature profiles require additional development, especially for the wall-fuel-film version of the Final Prechamber combustor.

RECOMMENDATIONS

The emission reduction technology demonstrated in this program has immediate, intermediate, and long-range potential application for aircraft gas turbine engines. Those concepts recommended for immediate potential application include:

- Extended-length combustion liners.
- Air-blast fuel injectors.
- Optimization of the number of primary holes and axial location.
- Delayed dilution - increased intermediate (trim) zone volume.
- Convection cooling instead of conventional film cooling.

The intermediate potential application is the incorporation of variable geometry. In addition to emission reduction, variable geometry offers other benefits such as improvement in altitude ignition, fuel-air turndown ratio, and liner durability. The latter advantage is due to reduced primary-zone flame temperatures at the high power conditions.

For long-range potential application, premix/prevaporization concepts such as the "Prechamber" combustor are recommended. The other potential concepts for long-range application are those which have an intense primary zone recirculation with rapid conversion to plug flow.

Although significant emission reduction technology was developed in this program, a continuing and expanded effort is recommended to further develop some of the concepts, investigate new concepts, and study problems encountered in this program.

In addition to the ecological incentive for low-mass-emission combustors, there are many other potential benefits from low-emission combustion systems, such as:

- Noise reduction.
- Altitude ignition and flame stability (lean blowout) improvement.
- Specific fuel consumption reduction, especially at idle and low power conditions.
- Increased combustor life due to (1) decreased liner temperature with reduced flame radiation, (2) reduced average primary-zone flame temperature, especially at high power conditions, and

(3) a more uniform flame temperature in the combustor and thus reduced liner temperature gradients and hot spots on the liner.

- Longer turbine section life due to demonstrated reduction in erosion with clean flames.

Additional analytical and experimental studies are recommended in the following areas:

- Variable geometry - Develop a simple, low-cost system for both can and annular combustors. A nonmechanical system such as fluidic control should be included in the study.

- Humidity effects - Conduct controlled experiments with water injection in the intake to determine the effect of humidity on NO_x and smoke (particulates).

- Durability - Conduct experiments to determine the effect of clean vs conventional combustors on the durability of gas turbine engine hot-section components.

- Heat transfer - Develop an effective, durable, low-pressure-loss, convection cooling system (and its design parameters) for can and annular combustors. Prior to this, determine the independent effect of using convection cooling instead of film cooling on emissions.

- Intermediate section - The results from the "Extended-Length" and "Delayed-Dilution" combustors demonstrated that the volume of the intermediate zone has a significant effect on emissions. Additional studies are recommended to predict and measure the effect of intermediate-zone temperature and residence time.

- Premix/Prevaporization combustors - The most promising premix/prevaporization combustor was the "Prechamber". However, additional studies are recommended to establish the design scaling parameters.

- Intense primary-zone recirculation/plug flow combustors - Further studies are recommended on these types of combustors to determine their potential for emission reduction. Two combustors recommended for further development studies are "Pepper-Pot Dome" and "Plug Flow/Canted Primary".

- Annular Combustors - Evaluate the potential application of the emission technology developed in this program for annular combustors. Select the applicable technology and evaluate the emission potential in annular combustor experiments.

- Emission instrumentation - Develop a rapid, on-line instrument for particulate measurements. Resolve the problem of NO_x emission data discrepancies with different measurement systems at less than 20 ppm.

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APPENDIX I
EXPERIMENTAL RESULTS OF BASELINE COMBUSTOR

The nonregenerative T63-A-5A gas turbine engine combustor liner was the baseline combustor liner used on this contract. It was against the emissions measured on this combustor liner that all low-emission combustor liners were compared. A photograph of the baseline T63 liner is shown in Figure 76. This standard production combustor system consisted of a dual-orifice pressure-atomizing fuel injector located in the center of the liner dome, a capacitive-discharge spark igniter located in the liner dome 1.25 inches off the liner axial centerline, and a "can"-type film-cooled combustor liner.

LINER PHYSICAL DESCRIPTION

The T63-A-5A combustor liner shown in Figure 76 is 9.56 inches long overall. The liner has film cooling in the dome, one film-cooling annulus at the dome exit, and one final film-cooling annulus of identical geometry located 1.83 inches downstream of the first film-cooling annulus. Liner hole sizes and locations are summarized in Table XXXVII. Using the dimensions in Table XXXVII, the resulting liner airflow splits based upon effective areas through the liner are tabulated in Table XXXVIII.

BASELINE T63-A-5A COMBUSTOR PERFORMANCE

Even though T63 engine emissions were used in the emission assessments in Task 1, testing of the T63-A-5A combustor was performed in the Research Combustion Test Facility early in the program. The rig tests accomplished two purposes. First, they provided a comparison of the emissions from the same combustor when tested in engine and rig environments; second, they provided a common base for the low-emission testing to follow. Any singular phenomenon common to the test facility would affect the emission/combustor performance of the baseline combustor in the same manner as the low-emission combustor.

The LOH duty cycle - T63 engine combustor operating conditions for the baseline nonregenerative combustor liner are given in Table XXXIX. The regenerative conditions are presented in Table XL. The combustor exhaust emissions resulting from the baseline T63-A-5A combustor when tested at these conditions are shown in Table XLI for regenerative as well as nonregenerative operation. These emissions have been plotted in Figures 77 through 80 as a function of percentage of engine output horsepower. It is clear from these figures that, operating at the higher reaction-zone temperatures of the regenerative combustor conditions, the baseline T63 combustor liner produced considerably less CO, C_xH_y, and particulates, but more NO_x emissions.

Figure 76. Baseline T63-A-5A Combustor Liner.

TABLE XXXVII. T63-A-5A LINER DESIGN SUMMARY

Item	Axial Location From Dome Exit (in.)	Liner Dia. (in.)	Type Opening	Number	Size (in.)
Dome Cooling	-	1.74-4.66	Holes	54	.203 dia.
First Cooling Annulus	.0	5.31	Slots	22	.39 x .10
Primary	1.40	5.31	Holes	6 6	.562 dia. .500 dia.
Second Cooling Annulus	1.83	5.31	Slots	22	.39 x .10
Trim	2.89	5.52	Holes	14	.375 dia.
Dilution	4.14	5.70	Holes	2	1.250 dia.
Exit	8.19	6.21	-	-	-

TABLE XXXVIII. BASELINE T63-A-5A LINER AIRFLOW AREA SLITS

Inlet Air Location	Airflow Area Split (%)
Dome Holes	11.8
First Cooling Step	11.2
Primary Holes	26.4
Second Cooling Step	11.2
Trim Holes	15.2
Dilution Holes	24.2
	100.0

TABLE XXXIX. T63-A-5A COMBUSTION SYSTEM OPERATING CONDITIONS FOR NONREGENERATIVE ENGINE AT SELECTED LOW DUTY CYCLE CONDITIONS

CYCLE POINT	MODE	POWER (shp)	POWER (%)	R_c	GAS GEN (rpm)	$TOT_{T/C}$ (°R)	Wa (lb/sec)	W_f (lb/hr)	BIT (°R)	BIP (psia)	$TIT_{F/A}$ (°R)	F/A
1	Ground Idle	33.5	10	3.03	36,500	1273	1.87	73.7	760	44.5	1502	.0105
2	Takeoff	335.0	100	6.28	52,450	[illegible]	3.22	229.5	[illegible]	92.3	2290	.0198
3	Climb Hover	251.0	75	[illegible]	48,600	[illegible]	2.98	178.5	932	81.0	2018	[illegible]
4	Cruise	[illegible]	55	4.47	45,700	[illegible]	2.75	143.5	890	71.5	1858	[illegible]
5	Descent	134.0	40	[illegible]	[illegible]	1437	2.53	119.0	857	63.7	1749	.0131
		84.0	25	[illegible]	[illegible]	[illegible]	2.20	95.0	813	[illegible]	[illegible]	.0121

TABLE XL. COMBUSTION SYSTEM OPERATING CONDITIONS FOR REGENERATIVE T63 SELECTED LOW DUTY CYCLE CONDITIONS

CYCLE POINT	MODE	POWER (shp)	POWER (%)	R_c	GAS GEN (rpm)	TOT (°R)	W_a (lb/sec)	W_f (lb/hr)	BIT (°R)	BIP (psia)	$TIT_{F/A}$ (°R)	F/A
1	Ground Idle	[illegible]	10	[illegible]	[illegible]	1250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	Takeoff	300.0	100	[illegible]	50,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	Climb Hover	210.3	75	5.12	[illegible]	[illegible]	[illegible]	122	[illegible]	[illegible]	2050	[illegible]
4	Cruise	[illegible]	55	[illegible]	[illegible]	[illegible]	2.42	101	1225	[illegible]	[illegible]	[illegible]
5	Descent	112.0	40	4.1	[illegible]	[illegible]	[illegible]	83	1175	50.2	[illegible]	[illegible]
		[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE XLI. COMPARISON OF T63 BASELINE LINER EMISSIONS/ COMBUSTOR PERFORMANCE AT (1) NONREGENERATIVE AND (2) REGENERATIVE COMBUSTOR OPERATING CONDITIONS

I. Conventional Liner - Nonregenerative	Cycle Point					
A. Emissions	1	6	5	4	3	2
CO, (ppm)	892.7	651.5	495.5	382.9	214.1	74.7
H/C, (ppm)	100.0	37.0	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.1	45.8	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Conventional Liner - Regenerative						
A. Emissions						
CO, (ppm)	346.2	242.5	196.8	142.9	85.8	38.0
H/C, (ppm)	8.8	2.6	1.6	1.5	3.3	1.5
NO_x, (On-Line, NDIR & NDUV) (ppm)	-	-	-	-	-	-
NO_x, (On-Line, CL) (ppm)	27.0	33.6	39.4	53.8	75.8	102.9
NO_x, (Saltzman) (ppm)	-	-	-	-	-	-
Smoke Number	2.00	.83	1.35	2.05	4.50	2.50
B. Pressure Loss (%)	6.50	6.52	7.00	6.85	6.27	6.64
C. Temp. Profile (T_{max}/T_{avg})	1.076	1.085	1.079	1.063	1.065	1.050

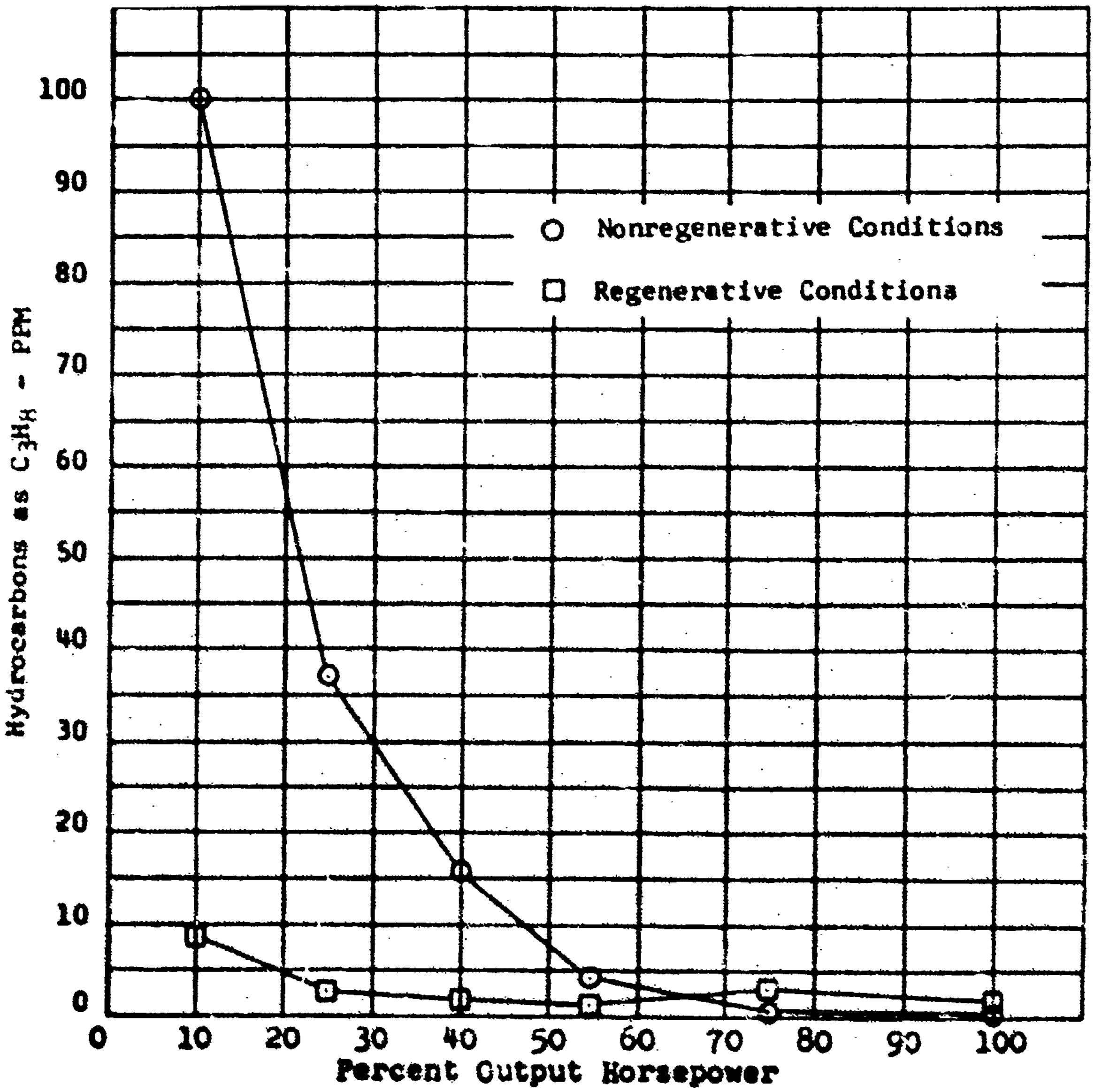


Figure 77. Conventional T63-A-5A Baseline Combustor Hydrocarbon Emissions Test Rig Data.

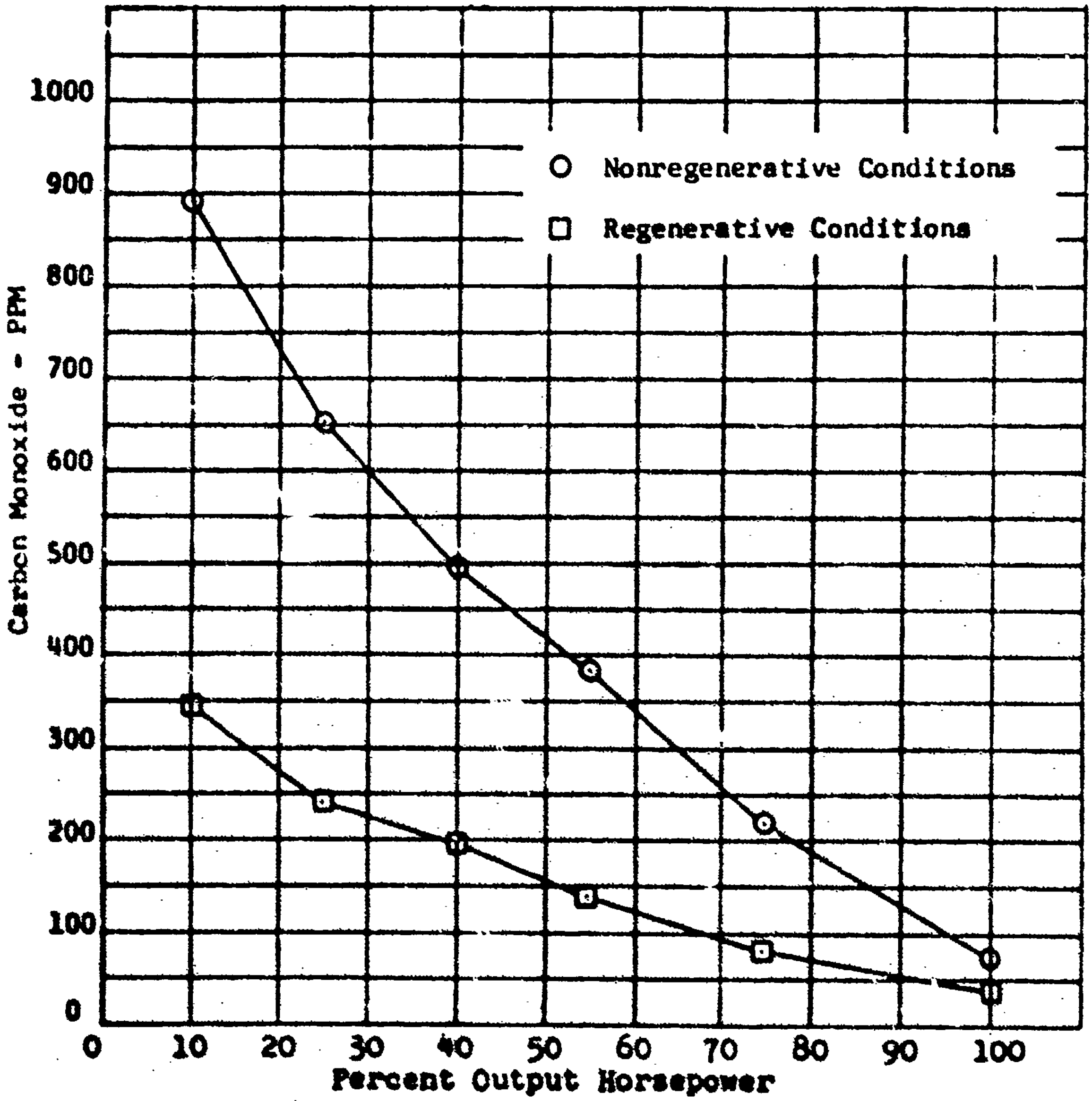


Figure 78. Conventional T63-A-5A Baseline Combustor Carbon Monoxide Emissions Test Rig Data.

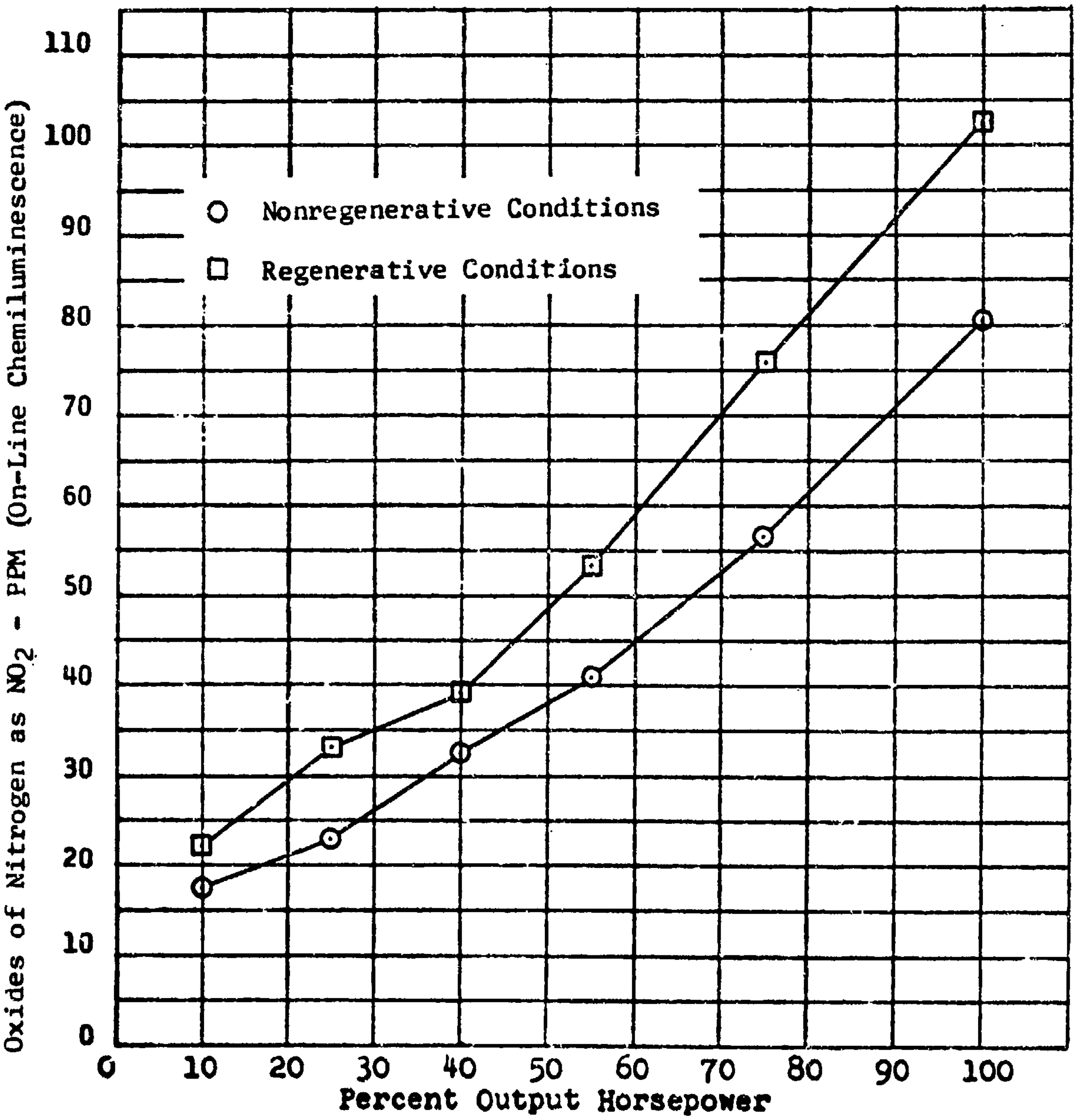


Figure 79. Conventional T63-A-5A Baseline Combustor
trogen Oxides Emissions Test Rig Data.

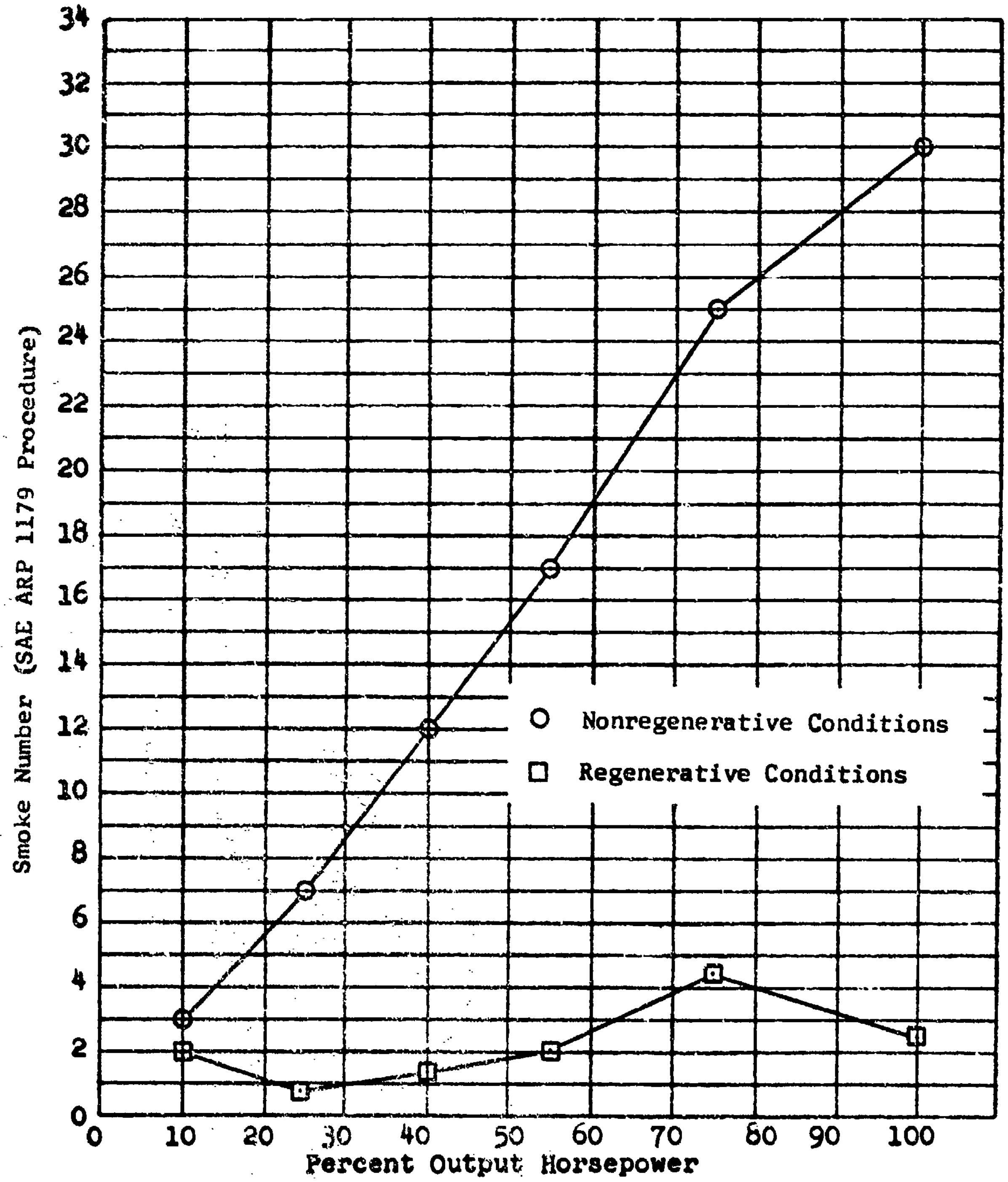


Figure 80. Conventional T63-A-5A Baseline Combustor Smoke Number Emissions Test Rig Data.

Using the emission data from Table XLI and Figures 77 through 80, the LOH duty cycle emissions indices for the baseline combustor liner at nonregenerative and regenerative operating conditions were computed. The constituent and total emissions index values are summarized in Table XLII along with the average fuel flow rates required for the LOH duty cycle. On a total mass basis, the baseline combustor produced an average of 4.63 lb/hr of total emissions at nonregenerative combustor operating conditions, but only 2.21 lb/hr of total emissions at regenerative conditions, based on the LOH duty cycle.

Pressure loss at regenerative conditions increased from an arithmetic average of 4.44% to 6.63% because of the higher loading produced by the increase in inlet temperature.

Exhaust temperature profile was very good at both nonregenerative and regenerative operating conditions. The arithmetically averaged temperature profile (T_{max}/T_{avg}) was 1.110 at nonregenerative conditions for the six data points and 1.070 for the regenerative conditions. The similarly averaged pattern factors were 0.1563 and 0.1517 for nonregenerative and regenerative conditions respectively.

This combustor's performance as measured in the test rig at the nonregenerative engine combustor operating conditions constituted the baseline against which all low-emission combustors tested on this contract were compared. The baseline LOH duty cycle total emissions index used in determining emission reductions was 32.946 lb emission/1000 lb fuel. This total index utilized the NO_x emissions measured with the on-line NDIR and NDUV instruments.

The similarity between T63 engine measured emissions and test rig measured emissions is shown in the comparison curves in Figures 81 through 83 for CO, C_xH_y, and NO_x. For particulates, the mass generation rates were plotted instead of smoke index; see Figure 84. In general, the engine hydrocarbons and particulates were somewhat higher than the levels measured on the combustion rig, but carbon monoxide and nitrogen oxides were slightly lower. Comparing the emission index values computed from these emission concentrations, Table XLIII, the total emissions from engine and rig measurements were nearly identical: 32.933 lb/1000 lb fuel for the engine and 32.945 lb/1000 lb fuel for the rig test.

BASELINE T63-A-5A COMBUSTOR RETESTS

After the seventeen preliminary combustors had been tested, a retest of the T63-A-5A baseline combustor was performed. Since the original baseline liner had been modified into one of the preliminary combustors, another production-fabricated combustor liner was purchased for the retest. In addition, the original dual-orifice pressure-atomizing fuel injector which had been

TABLE XLII. LOH DUTY CYCLE EMISSIONS FOR THE BASELINE T63-A-5A COMBUSTOR LINER

Emission	Emissions Index (lb emissions/1000 lb fuel) Nonregenerative Combustor Conditions	Regenerative Combustor Conditions
C_xH_y	1.544	.378
CO	26.094	13.804
NO_x*	5.068	8.412
Particulates	.239	.040
Total	32.945	22.634
Average Fuel Flow	140.65 lb/hr	97.64 lb/hr

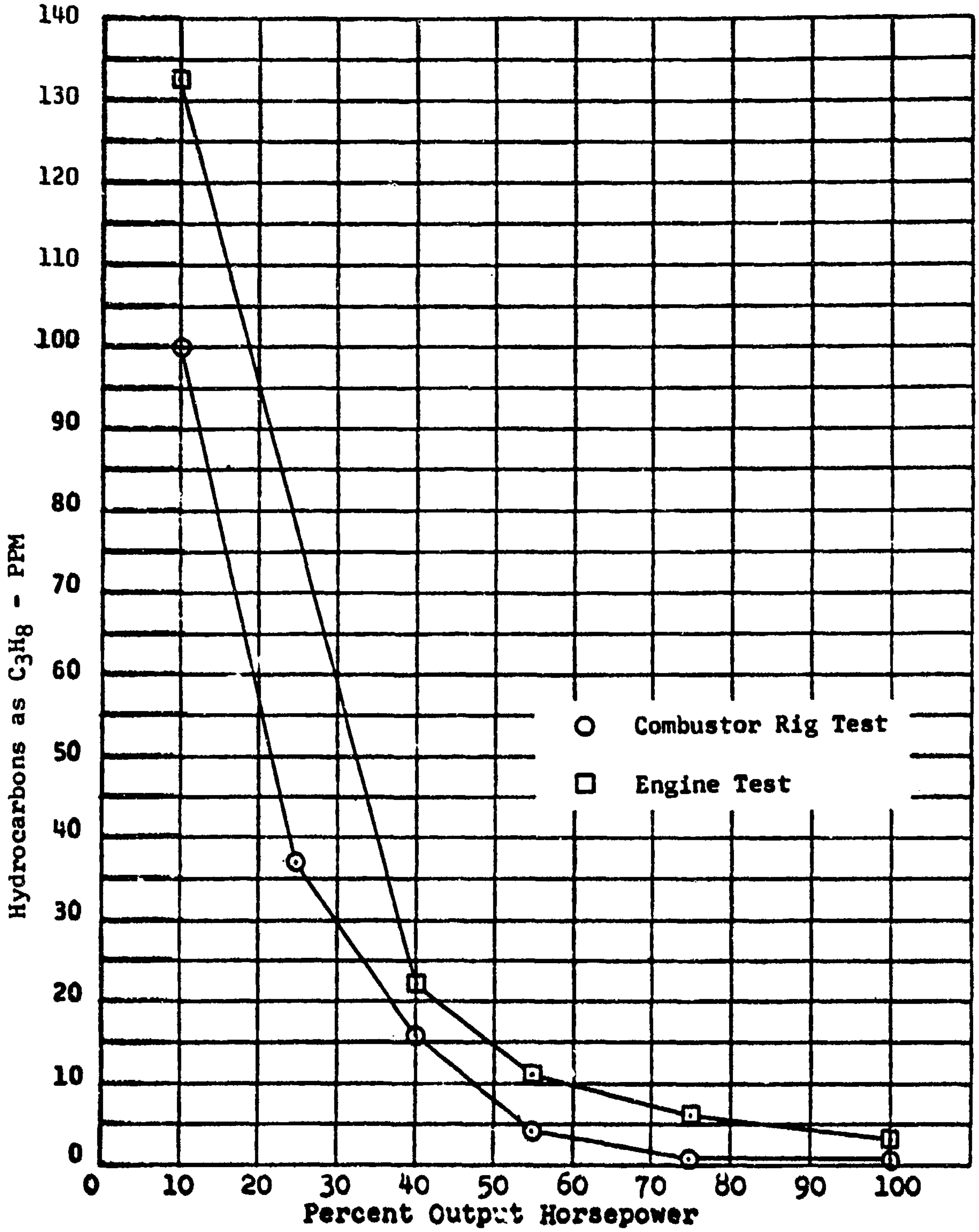


Figure 81. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Engine and Test Rig.

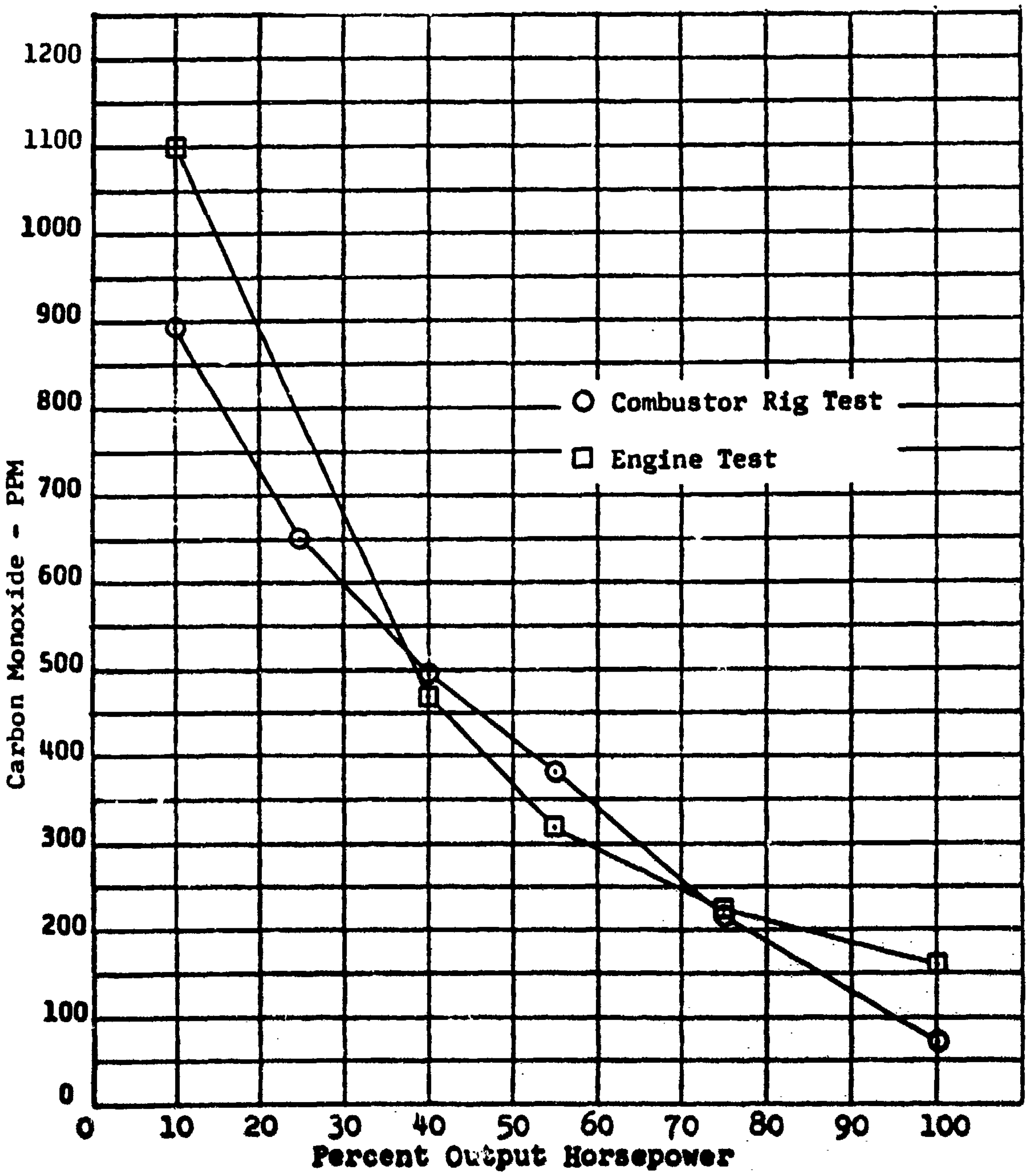


Figure 82. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Engine and Test Rig.

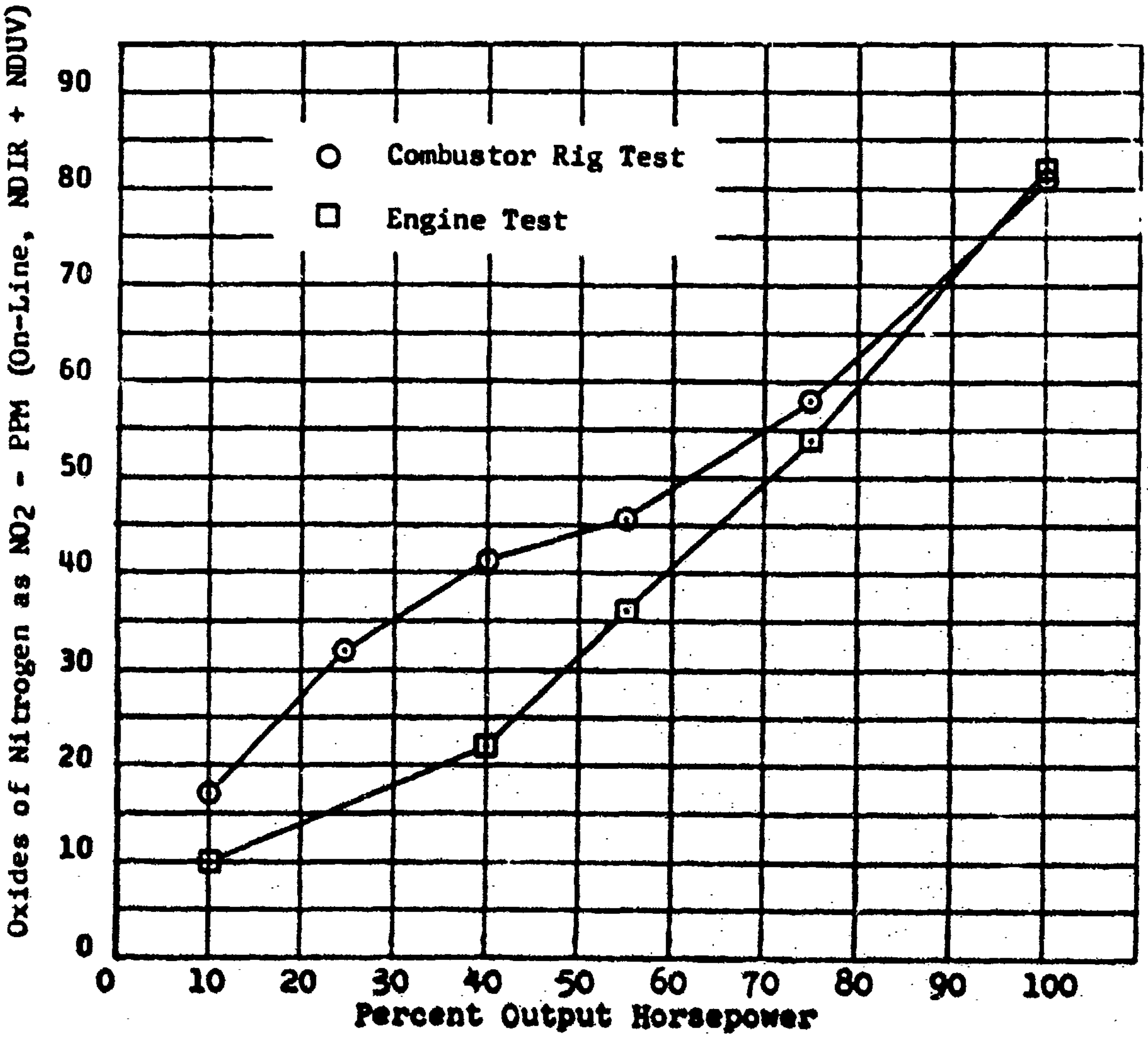


Figure 83. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Engine and Test Rig.

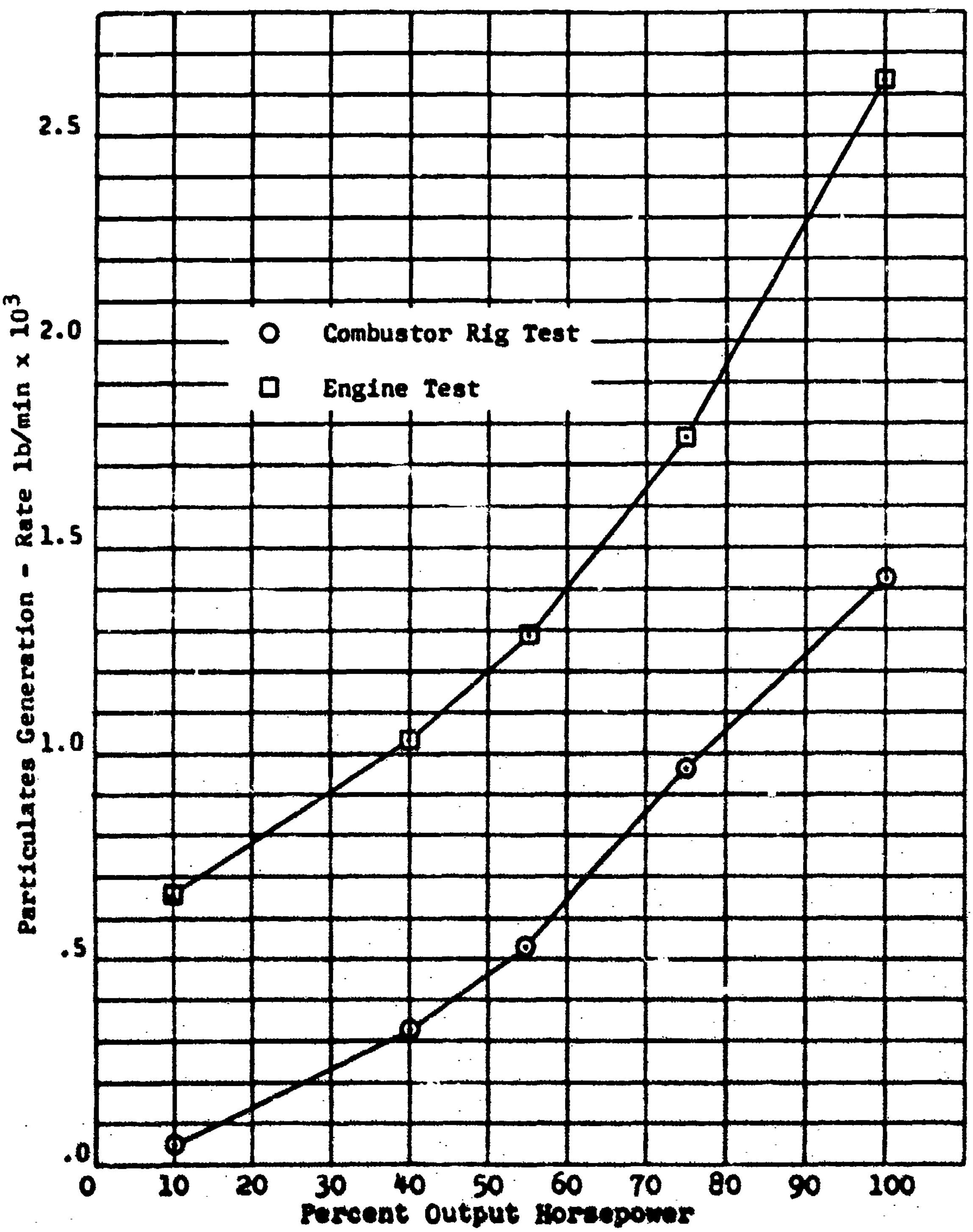


Figure 84. Nonregenerative T63-A-5A Combustor Mass Particulates Generation Rate Emission Data Comparison for Engine and Test Rig.

TABLE XLIII. COMPARISON OF T63-A-5A ENGINE AND COMBUSTOR RIG EMISSIONS FOR THE LOH DUTY CYCLE

	T63 Combustor Rig		T63 Engine	
Emission	lb/1000 lb Fuel	(%)	lb/1000 lb fuel	(%)
C_xH_y	1.544	100	2.467	160
CO	26.094	100	25.784	99
NO_x	5.068	100	4.118	81
Particulates	.239	100	.564	236
Total	32.945		32.933	

used in all of the preliminary combustor testing requiring a pressure-atomizer injector, was replaced in the retest with another available fuel injector. The retest was performed on June 7, 1972, and the resulting emissions/combustor performance deviated markedly from the initial test. The tabulated test results are given in Table XLIV.

Comparison of the constituent emissions revealed that CO and C_xH_y increased slightly, NO_x decreased significantly, and particulates (smoke index) increased alarmingly. Pressure losses between tests at the same operating conditions showed that the effective liner flow-through areas were acceptably consistent. This, in fact, was determined physically, as all hole and cooling slot sizes were checked after the test and were found to be within manufacturing tolerance.

Because of the degradation in exhaust temperature profile (T_{max}/T_{avg}) in the retest, the fuel injector was bench tested and was found to exhibit a 31-degree circumferential fuel flow distortion. This magnitude of distortion was outside the production acceptance specification. Excessive circumferential flow distortions from a fuel injector can produce a nonuniform temperature pattern and cause emissions to increase

To prove the repeatability of the combustor emissions and performance, another retest was scheduled, but first a new fuel injector was secured and bench tested to assure that its performance was acceptable. The results of the fuel injector bench test showed that the flow vs pressure drop performance was within specifications and that the circumferential flow distortion was only half the allowable variation. The second baseline combustor retest was conducted on July 31, 1972. The emission results of this test, the first retest, and the initial test are presented in Table XLIV. The curves in Figures 85 through 88 compare the individual emissions from all three baseline tests. The repeatability of CO and C_xH_y emissions is evident for the initial test and second retest in Figures 85 and 86. The small differences observed between these two sets of emissions can easily be attributed to experimental variations and not differences between the combustors.

The NO_x and smoke number data in Figures 87 and 88 show that it was the retest emissions data which repeated. For both retests, NO_x was substantially below the initial test NO_x concentrations, and similarly, both retest smoke number data were themselves consistent but a factor of two or more higher in magnitude than the initial smoke numbers.

Emission index values for all three baseline combustor tests were computed from the emission concentrations listed in Table XLIV and plotted in Figures 85 through 88. The results of these

TABLE XLIV. COMPARISON OF T63 NONREGENERATIVE EMISSION/ COMBUSTOR PERFORMANCE OF CONVENTIONAL BASELINE T63-A-5A COMBUSTOR LINERS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner - Initial Test (11-9-71)						
A. Emissions						
CO, (ppm)	892.7	651.5	495.5	382.9	214.1	78.7
H/C, (ppm)	100.0	37.0	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.9
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
No_x, (Saltzman) (ppm)	18.5	27.8	37.1	45.8	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Conventional Liner - Retest (6-7-72)						
A. Emissions						
CO, (ppm)	966.5	651.5	525.3	461.9	289.6	112.4
H/C, (ppm)	101.0	60.0	25.0	11.2	2.1	.8
NO_x, (On-Line, NDIR & NDUV) (ppm)	20.7	25.7	35.9	39.2	49.3	70.6
NO_x, (Saltzman) (ppm)	14.4	20.7	29.1	37.3	51.2	72.9
Smoke Number	8.69	23.50	34.34	46.56	58.60	55.84
B. Pressure Loss (%)	4.62	4.22	4.43	4.34	4.33	4.05
C. Temp. Profile (T_{max}/T_{avg})	1.207	1.210	1.161	1.174	1.158	1.121
III. Conventional Liner - Retest (7-31-72)						
A. Emissions						
CO, (ppm)	856.6	651.5	465.2	351.0	242.5	97.4
H/C, (ppm)	79.0	38.0	14.4	4.6	1.1	.0
NO_x, (On-Line, NDIR & NDUV) (ppm)	18.6	25.2	32.4	37.5	49.0	68.3
NO_x, (Saltzman) (ppm)	19.9	28.1	34.6	44.9	55.2	78.6
Smoke Number	10.27	20.87	30.59	43.92	50.02	56.36
B. Pressure Loss (%)	4.46	4.37	4.32	4.24	4.02	3.91
C. Temp. Profile (T_{max}/T_{avg})	1.095	1.143	1.155	1.152	1.141	1.148

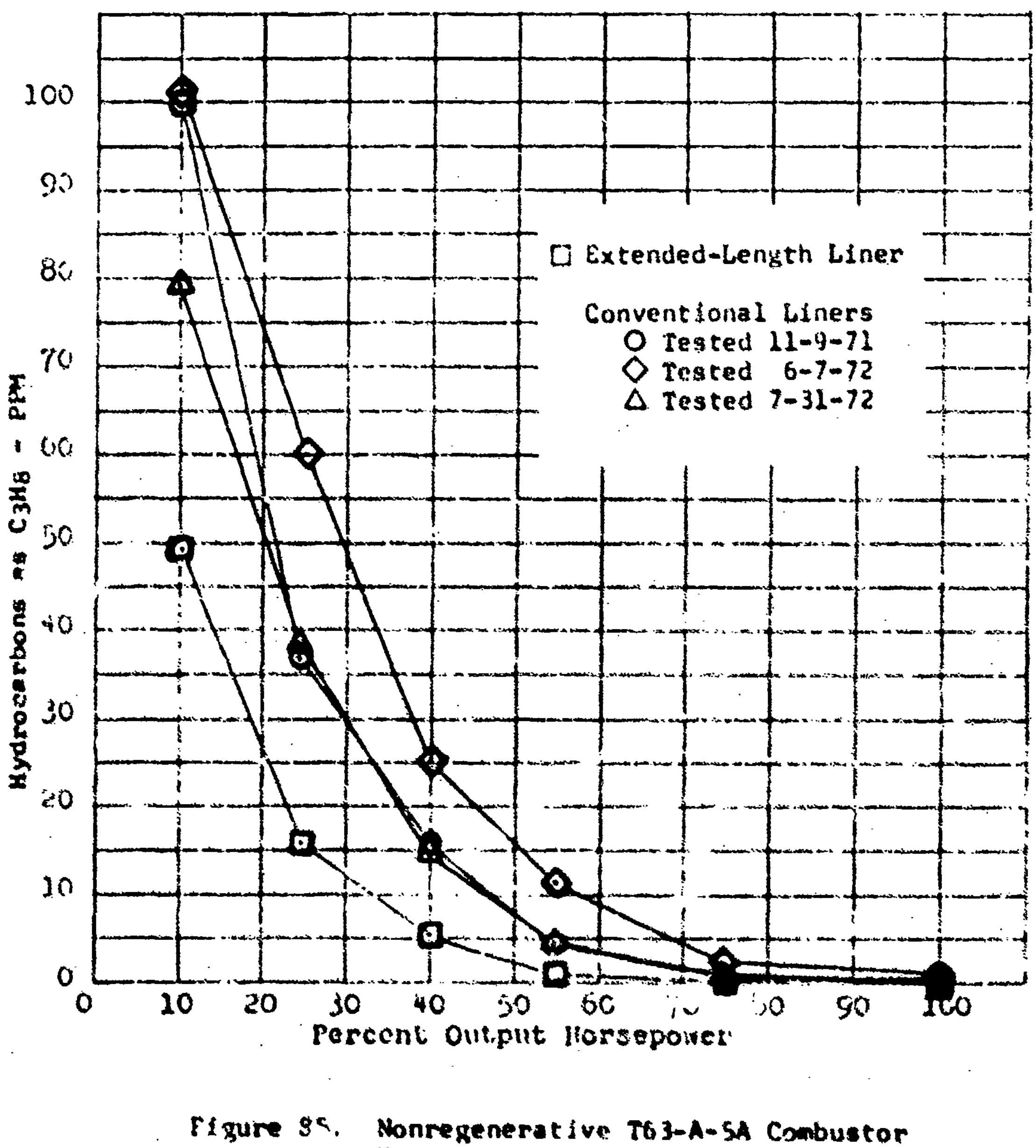


Figure 85. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Baseline T63 Combustor Liners.

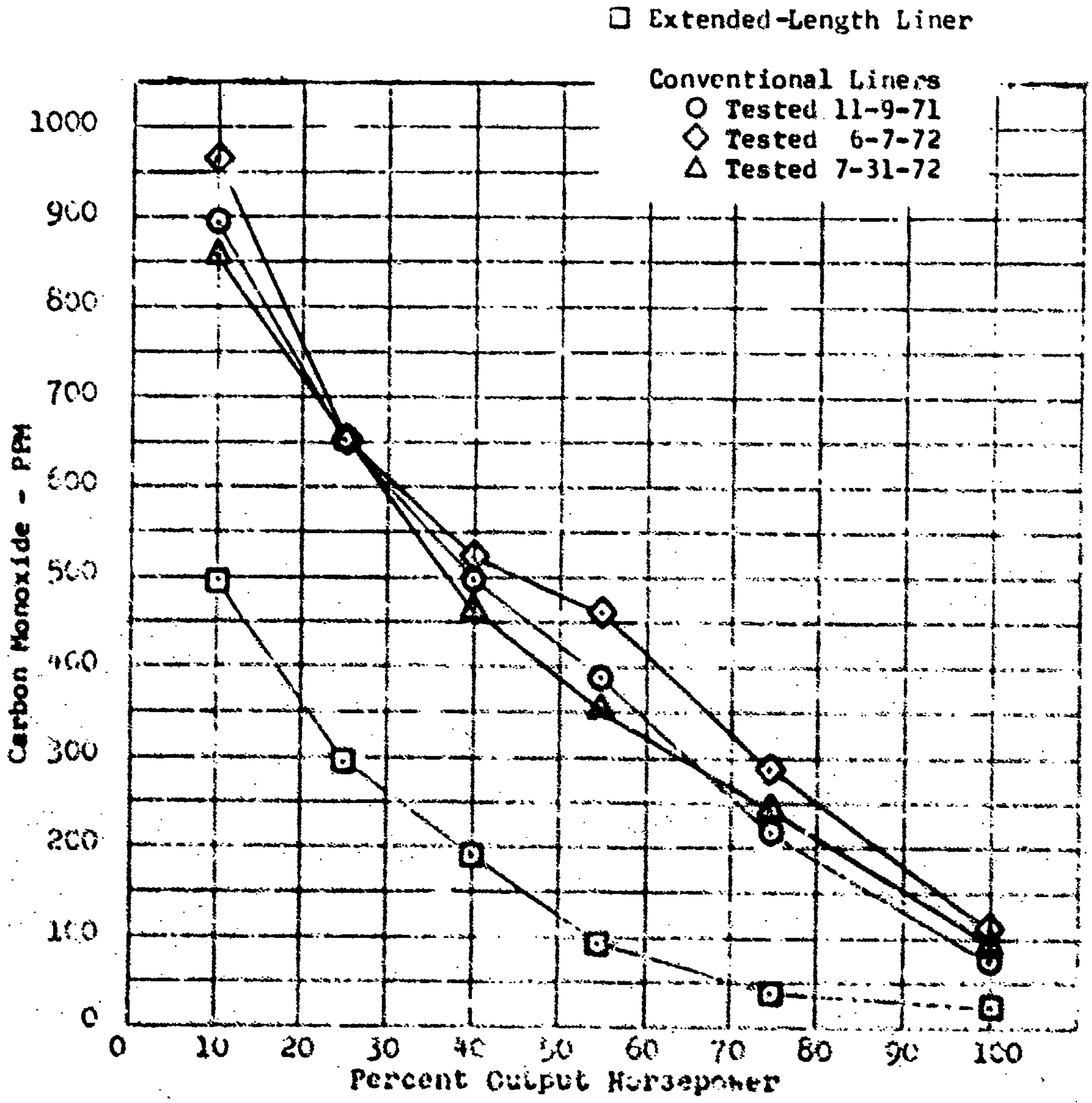


Figure 86. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Baseline T63 Combustor Liners.

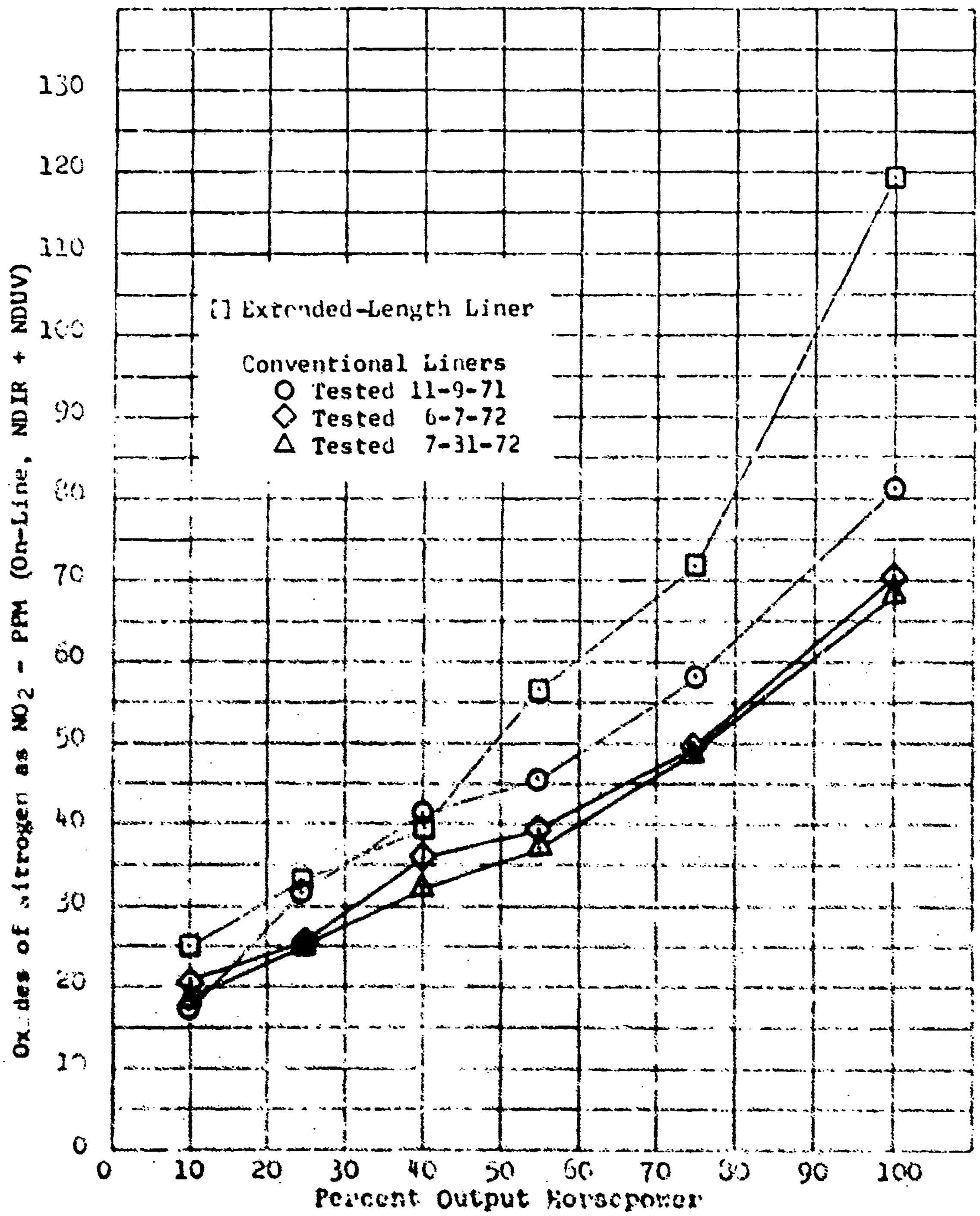


Figure 87. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Baseline T63 Combustors Liners.

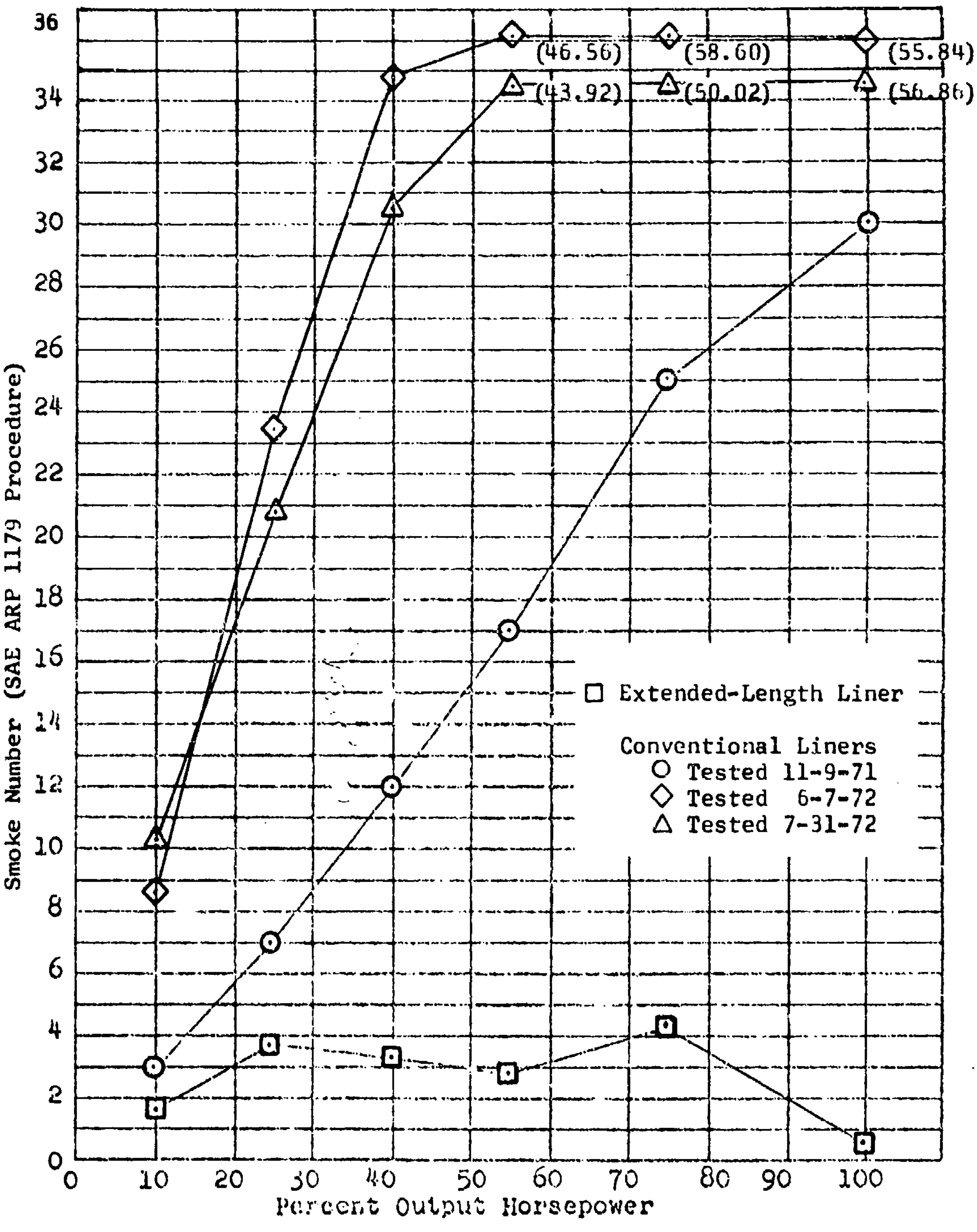


Figure 88. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Baseline T63 Combustor Liners.

calculations are summarized in Table XLV. Shown here are the values of constituent as well as total emissions indexes In the top half of the table, the EI values are tabulated in units of lb emission/ 1000 lb of fuel; in the bottom half of the table are relative EI values, based upon the initial test results. It is clear from the total emissions column that the initial test (11/9/71) and the second retest (7/31/72) data repeat very well, and that the first retest exhibited a significant increase in total emissions. It is also easily seen which magnitudes of the constituent emissions repeat and which do not repeat.

The search for an explanation of the differences in constituent emissions showed that the poor circumferential flow distribution of the fuel injector used in the first retest was responsible for the shift to higher CO and C_xH_y emissions in that test, since the new fuel injector used in the second retest returned these emissions to approximately their initial concentrations. This conclusion is supported by examination of the temperature profile data plotted in Figure 89. In this figure the conventional liner initial test baseline profile is indicated along with other recorded profiles for that combustor taken during the same period of time. The reason for the variation in profile values is simply a reflection of the fluctuating behavior of the exhaust as it exits the combustor. Temperature profile changes of these magnitudes are typical of all of the tests conducted; thus either an average value over a reasonable time period should be used to quantify the profile or a band containing the typical fluctuations should be used. This latter idea has been indicated in Figure 89 by the portion of the graph labeled "Conventional Liner Profile Band." The temperature profile designated as "baseline" typically corresponded to the lower edge of that band.

The first retest profile is also plotted on this curve, and these data are consistently at or above the upper edge of the initial test profile band. This supports the contention that the fuel injector in the first retest was functioning improperly. The second retest temperature profile (7/31/72) shows an overall improvement when compared to the first retest. Four values are within the profile band, one value is above, and one value is below.

The temperature profile improvement with the new fuel injector did not return the NO_x and smoke number readings to the initial test levels. In fact, the NO_x and smoke repeated quite well with the first retest data. Since the initial test was conducted in the late fall and the retests were conducted in the summer, the effect of seasonal differences on the combustor inlet air or changes in the fuel during the interim might help to explain the changes in NO_x and smoke. All combustor testing on this contract was performed with JP-4 fuel. The DDA Test Department had conducted emission measurements on another engine using JP-5 fuel, also in the winter

TABLE XLV. EMISSION INDEX SUMMARY FOR CONVENTIONAL T63-A-5A COMBUSTORS

Test Date	EMISSION CONSTITUENT C_xH_y	CO	NO_x*	Particu-lates	Total Emissions
Actual Emission Index (lb/1000 lb Fuel)					
11/9/71	1.544	26.094	5.068	.239	32.945
			5.189		33.066
6/7/72	2.067	30.569	4.427	1.422	38.485
			4.216		38.274
7/31/72	1.323	25.080	4.241	1.100	31.744
			4.881		32.384
Relative Emission Index (%)					
11/9/71	100	100	100	100	100
			102		100
6/7/72	134	117	87	595	117
			83		116
7/31/72	86	96	84	460	96
			96		98

*First NO_x Line is for On-Line NDIR + NDUV.
Second NO_x Line is for Saltzman.

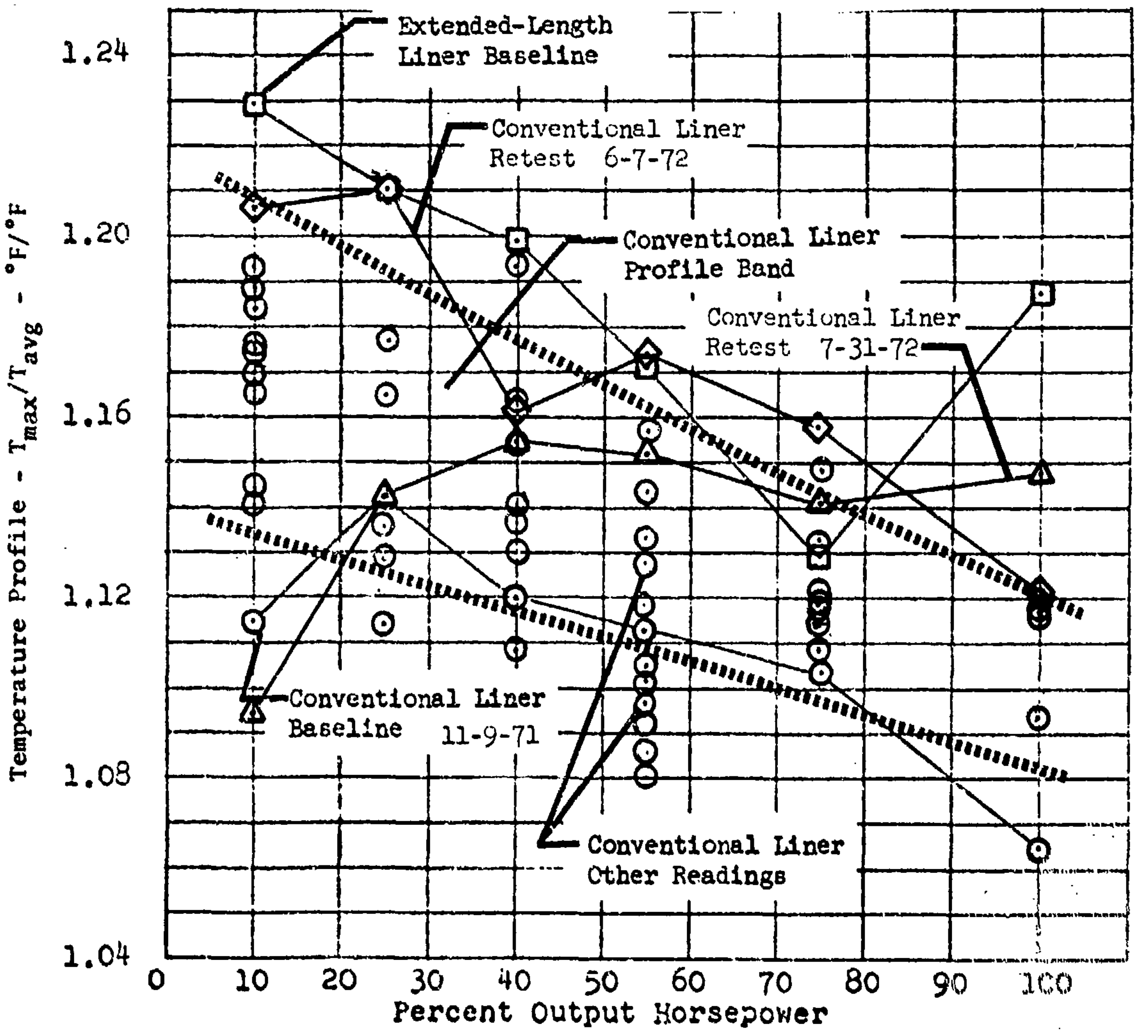


Figure 89. Nonregenerative T63-A-5A Combustor Temperature Profile Comparison for Baseline T63 Combustor Liners.

and summer, and had observed similar differences in NO_x and smoke between the seasonal tests. Therefore, it was discounted that changes in fuel had caused the differences in NO_x and smoke.

It is known that water vapor has a significant effect on nitric oxide emissions.[32] With this phenomenon in mind, relative humidities for the test dates of the baseline combustor were obtained from DDA Facilities Department records, and absolute atmospheric humidities experienced during each test were determined. The on-line NDIR + NDUV NO_x concentrations for each baseline test were plotted as a function of the atmospheric absolute humidity for lines of constant power, see Figure 90. The trend of NO_x decrease with moisture content increase is compatible with the predictions of Moore.[32]

Perhaps, of even more significance was the seeming correlation of smoke number increase with air moisture content, as can be seen in Figure 91. Examination of these curves reveals that between the first test and the second retest, the smoke number significantly increased for the same quality of combustor components, liner, and fuel injector. The peaking of the smoke numbers from the first retest was probably a result of the poor distribution from the fuel injector.

It therefore appears from the experimental data recorded from this test program that both NO_x concentrations and smoke number may be influenced by the concentration of moisture in the combustor inlet air. Future testing should be conducted with this observation in mind, and inlet combustor air moisture content should be measured in addition to the standard inlet parameters.

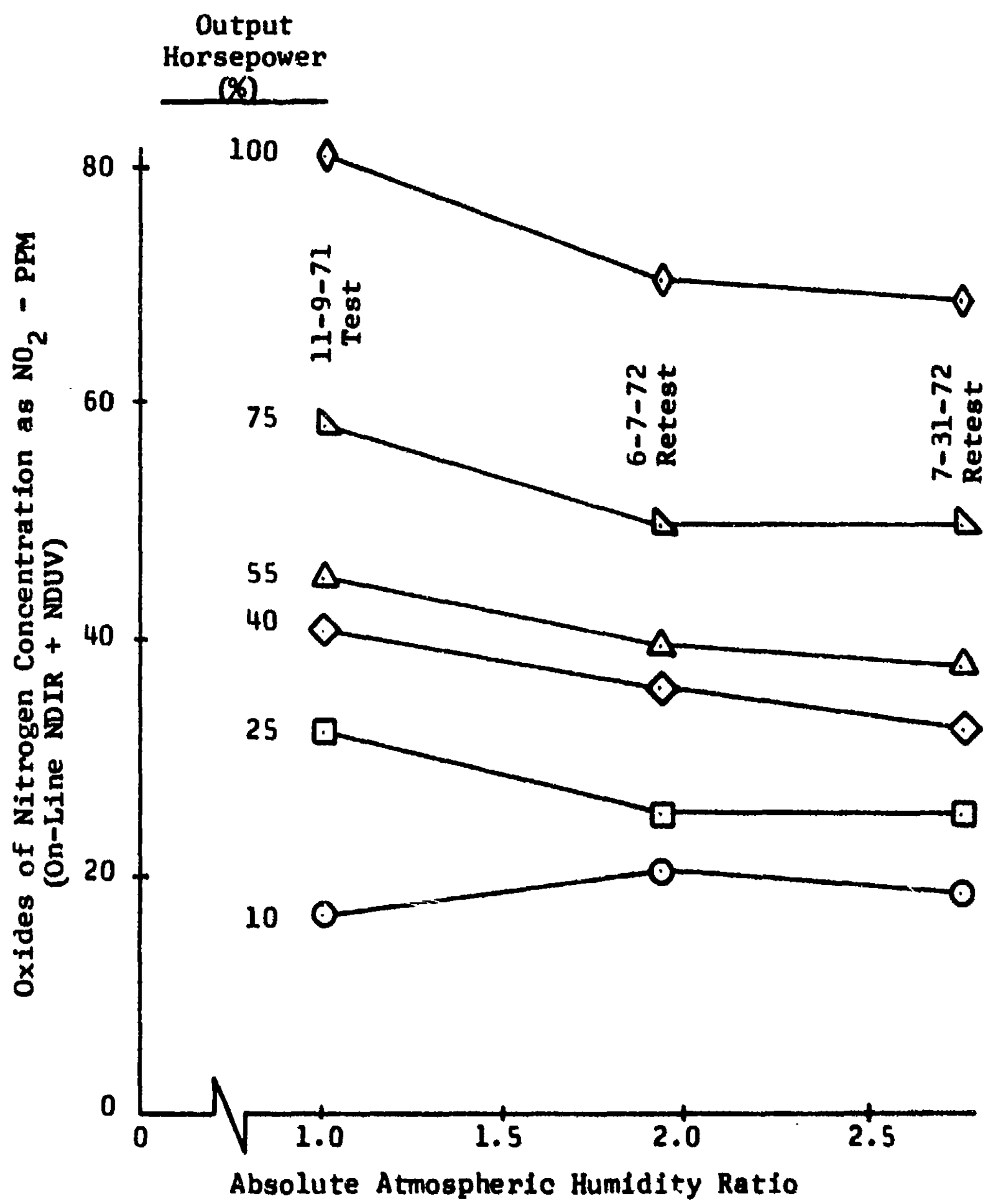


Figure 90. Conventional T63-A-5A Nitrogen Oxides Variation With Atmospheric Humidity.

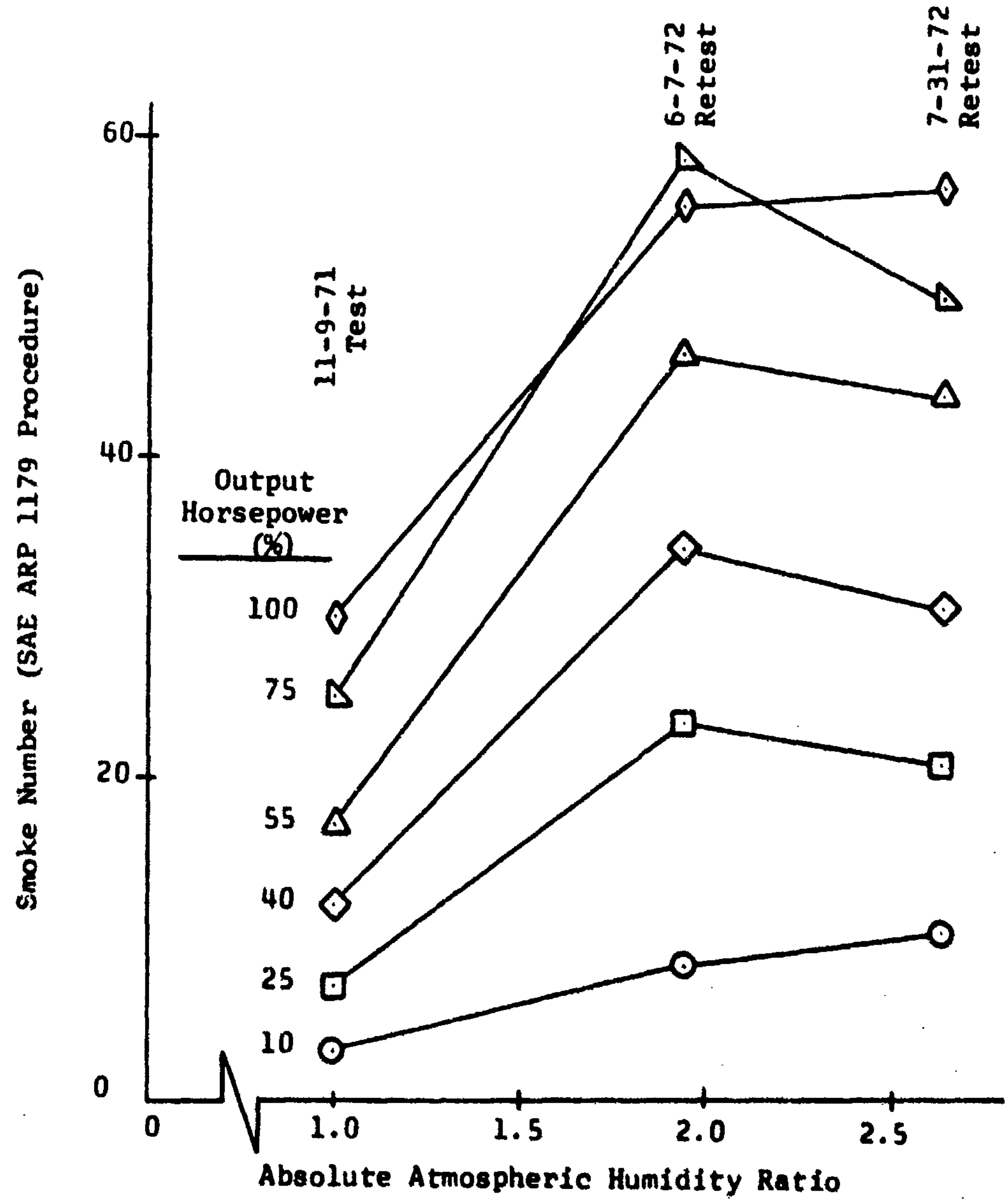


Figure 91. Conventional T63-A-5A Smoke Number Variation With Atmospheric Humidity.

APPENDIX II
DESIGN AND EXPERIMENTAL RESULTS OF PRELIMINARY LOW-EMISSION COMBUSTORS

The following seventeen combustors were designed and tested to determine preliminary emission performance data.

- Extended Length
- Rich Primary Zone
- Air Blast/Air Assist
- Variable Geometry
- Early Quench
- Delayed Dilution
- Delayed/Annular Dilution
- Premix Cup/Gaseous Fuel
- Plug Flow/Canted Primary
- Tangential Swirl
- Swirl Dome
- Rich Premix/Swirl
- Pepper-Pot Dome
- Delayed Quench
- Premix/Prevaporization
- Prechamber
- Optimum Primary

The approach was to obtain a low-cost, rapid evaluation of each of the above concepts. The best concept or concepts would then be designed into the final configuration(s) as discussed in Appendix III and Appendix IV to meet the contract objectives. Detailed experimental reports were published on each of the combustors and are available upon request. This appendix presents a summary of those reports for each of the combustors which were evaluated at primarily the T63-A-5A nonregenerative combustor operating conditions presented in Table IV.

As shown in that table, six steady-state operating conditions were defined from idle through maximum power. Most of the above-listed combustors were tested at all six conditions, but a limited number of combustors were tested at fewer sets of conditions due to combustor operational problems. However, some of the combustors, such as the "Variable-Geometry Combustor", were tested at many additional conditions. Thirty lines of data were obtained, including both nonregenerative and regenerative conditions. Furthermore, some of the seventeen combustors were modified and retested. A total of 177 lines of experimental data were obtained for the seventeen preliminary low-emission combustors.

Sixteen of the combustors were tested with JP-4 fuel; the other combustor, "Premix Cup/Gaseous Fuel", was tested with gaseous propane. The total emission indexes were calculated from the experimental emission data for the seventeen preliminary low-emission combustors. The calculations were made for the previously defined LOH duty cycle and the T63 nonregenerative engine. These results could then be compared as shown in Table XLVI with the baseline combustor to determine the potential of the concepts for meeting the contract emission reduction objectives. These objectives are to reduce the total emissions 50% without an increase in any individual emission. As shown in Table XLVI, eight of the preliminary combustors met the 50% emission reduction objective, but only the "Prechamber" combustor met the second objective of no increase in the individual emissions. However, a combination of some of the separate features in the seventeen preliminary combustors might be combined into a combustor to meet the contract objectives. This in fact was done; therefore, two combustors were selected from this preliminary evaluation for further experimental evaluation as reported in Appendixes III and IV. These were the "Prechamber" and "Modified Conventional."

This appendix reports only on the design and experimental results from the preliminary low-emission combustors. Each of the combustors is discussed separately in the following sections.

EXTENDED-LENGTH COMBUSTOR

Task 2 analytical studies predicted that significant reductions in CO and C_xH_y could be achieved by increasing the residence time in the intermediate zone. This intermediate zone is the section between the primary zone and the dilution zone. The calculations show that at the intermediate zone temperatures, the CO, C_xH_y and C could be consumed with only small increases in NO_x.

A T63-A-5A combustor was modified to obtain the "Extended-Length" combustor. The only modification, as shown in Figure 92, was to add a 6-inch cylindrical section between the primary holes and the first row of dilution holes.

TABLE XLVI. RELATIVE EMISSION INDEX PERFORMANCE OF PRELIMINARY LOW-EMISSION COMBUSTORS

COMBUSTOR	RELATIVE EMISSIONS INDEX, %					
	C_xH_y	CO	NO_x	PARTICULATES	TOTAL EMISSIONS	CYCLE POINTS
T63-A-5A Baseline	100	100	100	100	100	5
Extended Length	44	33	124	14	48	5
Rich Primary Zone	63	65	110	321	73	5
Air Blast/Air Assist						
• DDA Air Blast	136	105	108	15	106	5
• Ex-Cell-O Air Blast	155	100	87	36	100	5
• Ex-Cell-O Air Assist	216	102	73	74	103	5
Variable Geometry						
• Constrained	35	56	103	22	62	5
• Unconstrained	20	32	121	29	45	5
Early Quench	248	70	128	74	84	4
Delayed Dilution	65	54	99	41	62	5
Delayed/Annular Dilution	77	60	91	156	66	5
Premix Cup/Gaseous Fuel	1800	211	135	a	440	1
Plug Flow/Canted Primary						
• Initial Design	315	108	100	181	117	5
• Mod. "A"	55	47	116	709	63	5
Tangential Swirl	1380	88	106	17,090	285	1
Swirl Dome	52	32	116	185	47	5
Rich Premix/Swirl	3	11	121	58	28	5
Pepper-pot Dome	24	34	133	1	49	5
Delayed Quench	54	52	109	541	64	5
Premix/Prevap.	106	50	100	a	58	1[b]
Prechamber						
• Initial Design	92	37	50	0	41	5[c]
• Richer Primary	52	24	70	0	32	5[d]
Optimum Primary	27	29	126	11	44	5

a No data taken
b Adjusted design point
c Based on extrapolated data for idle and max. power
d Based on extrapolated data for max. power

Figure 92. Preliminary Low-Emission Extended-Length Combustor Liner.

The "Extended-Length" combustor was tested with the T63-A-5A conventional pressure-atomizing fuel injector and spark ignition system. JP-4 fuel was used in the experiments. The combustor was tested at six steady-state conditions defined in Table IV. These simulated conditions correspond to the combustor conditions for the T63-A-5A nonregenerative engine operating at idle (10% power) through maximum power.

The CO emissions from the "Extended-Length" combustor were significantly less than those from the T63-A-5A conventional, baseline combustor, as shown in Figure 93. Similarly, as shown in Figure 94, the C_xH_y emissions were also reduced significantly. However, the NO_x emissions from the "Extended-Length" combustor were more than those from the T63-A-5A combustor, as shown in Figure 95. The higher NO_x was due to the increased residence time. The smoke, like the CO and C_xH_y, was also significantly reduced from the "Extended Length" combustor. As shown in Figure 96, the smoke was reduced to very low values at all operating conditions including maximum power. The same amount of carbon was probably formed in the primary zone, but it was consumed during the long residence time section in the intermediate zone of the combustor.

The emission data from the "Extended-Length" combustor presented in Figures 93 through 96 were used to calculate the emission indexes for the previously defined T63 powered, LOH duty cycle. These emission indexes for the "Extended Length" combustor were compared to the T63-A-5A baseline combustor and show the following effects on emission performance:

- C_xH_y emissions were reduced 56%.
- CO emissions were reduced 67%.
- NO_x emissions were increased 24%.
- The particulates were reduced 86%.

As shown in Table XLVI, the net effect was a 52% reduction in total emissions. This met the first contract objective to reduce the emissions 50%. However, it did not meet the contract objective of no increase in individual emissions because the NO_x increased 24%. Furthermore, the reduction was not achieved in the same combustor envelope. The tests were significant, however, for two reasons:

- A very simple change in the combustor can provide significant reductions in total emissions.
- A properly designed, optimized trade-off in the primary zone/intermediate zone/dilution zone will undoubtedly

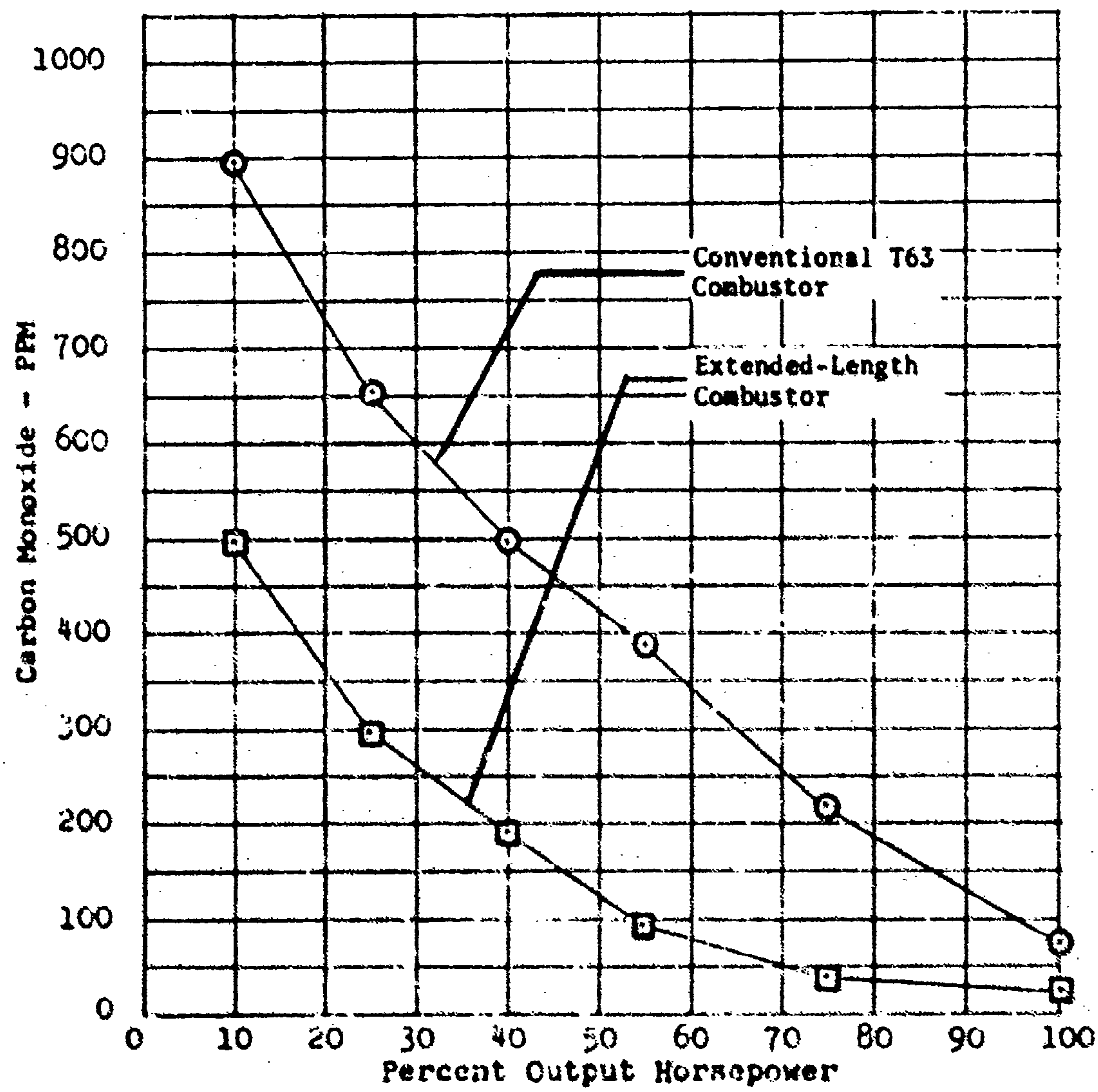


Figure 93. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison With Extended-Length Combustor Liner.

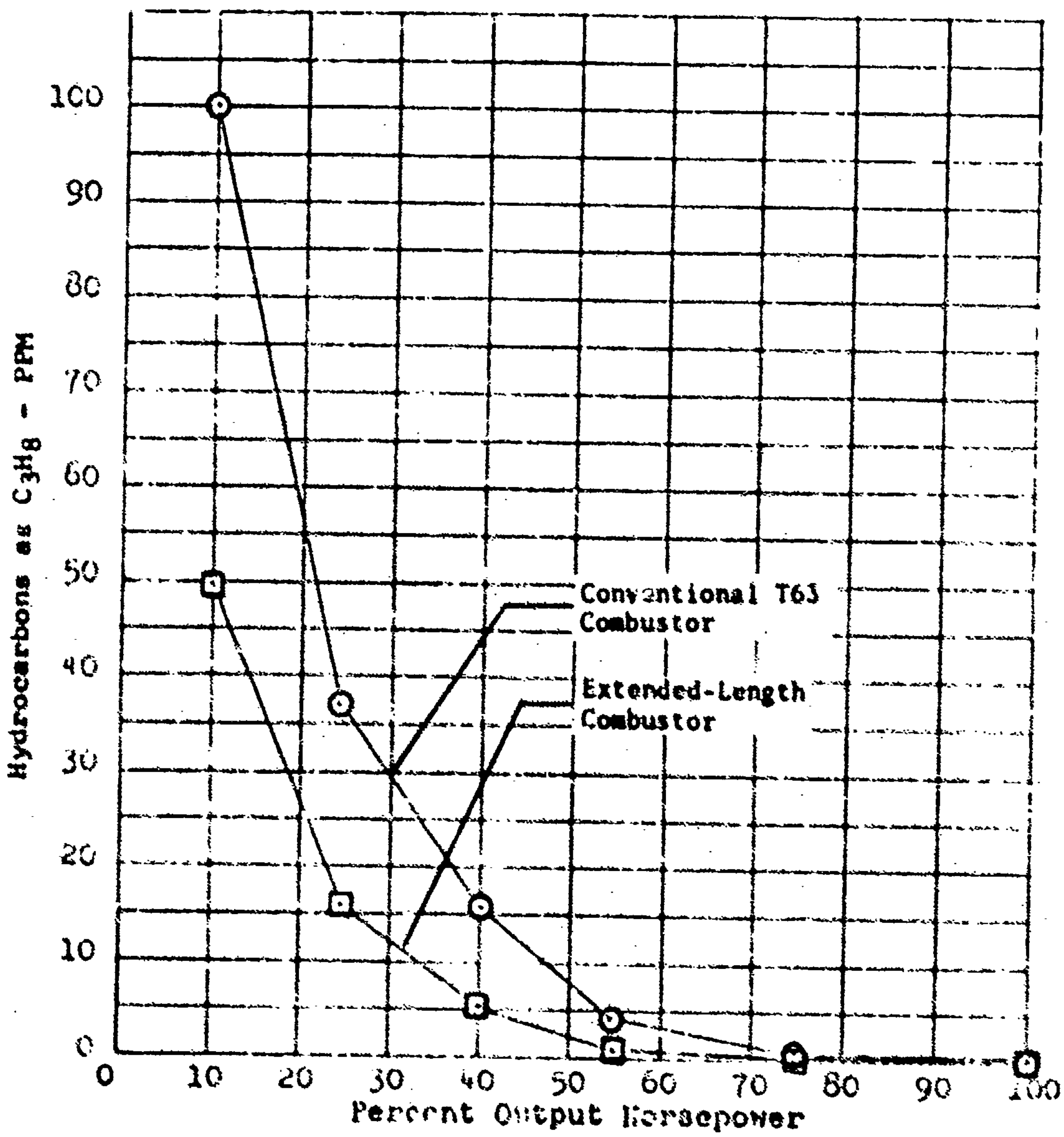


Figure 94. Nonregenerative 63-A-5A Combustor Hydrocarbon Emission Data Comparison With Extended-Length Combustor Liner.

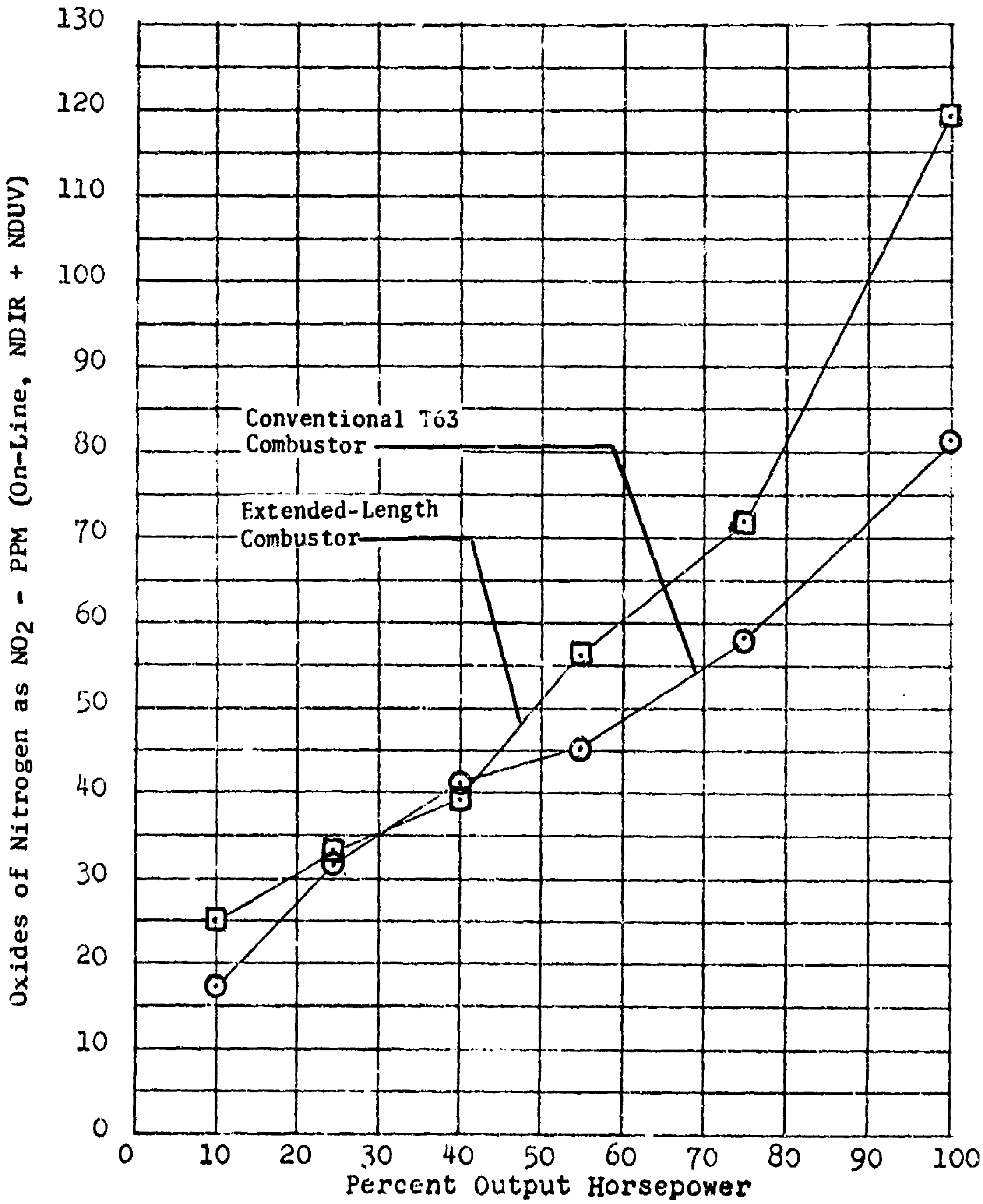


Figure 95. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison With Extended-Length Combustor Liner.

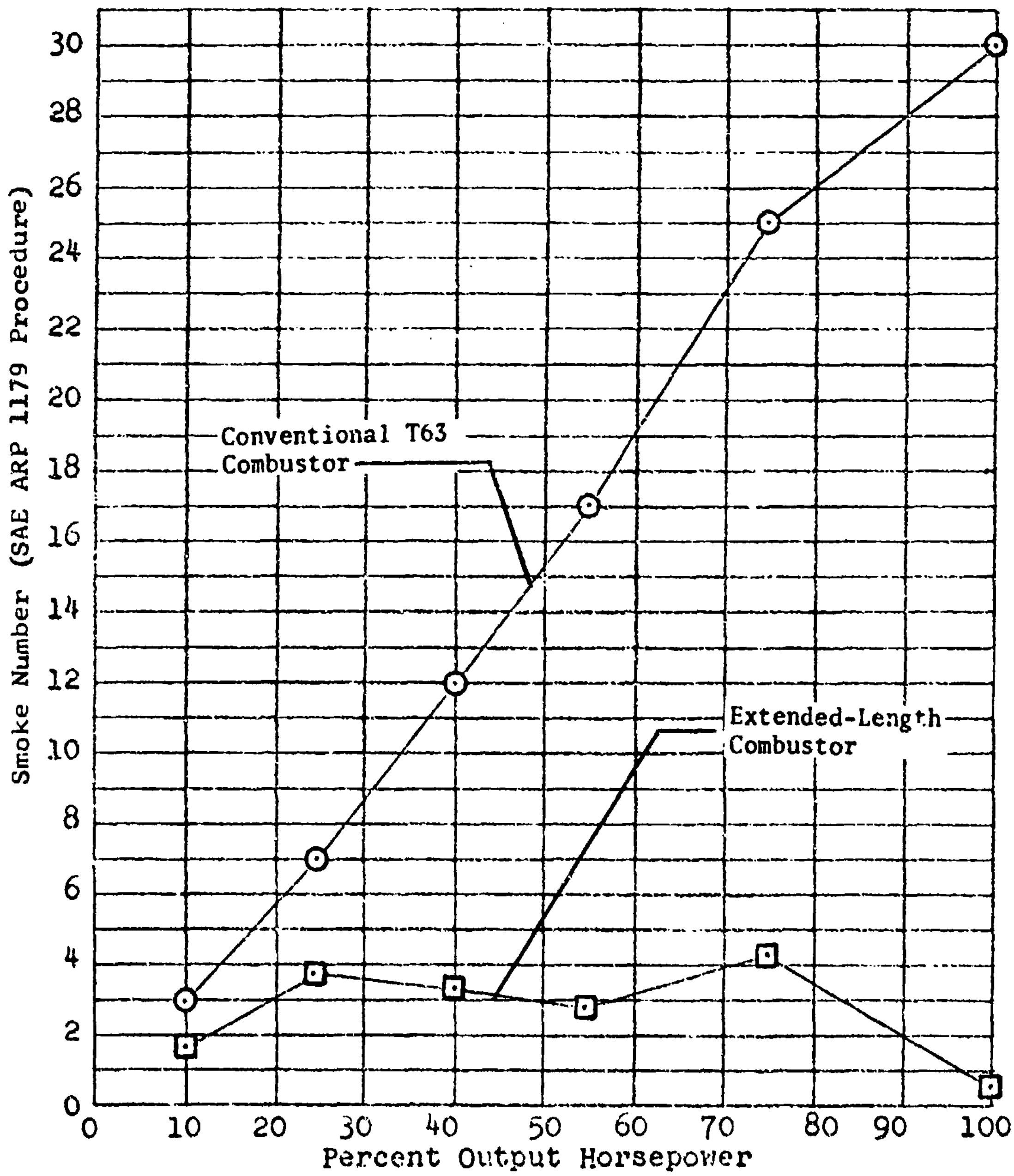


Figure 96. Nonregenerative T63-A-5A Combustor Smoke Comparison With Extended-Length Combustor Liner.

provide significant reductions in total emissions even within the same combustor envelope.

The only surprise from the experiments was the degradation in temperature profile as shown in Figure 97. Previous and subsequent experiments have shown that the T63-A-5A is very sensitive to the external aerodynamic flow between the liner and outer combustor case. With the extended length, the airflow into the dilution was probably unbalanced slightly and led to the degradation in temperature profile shown in Figure 97. A careful tailoring of the dilution zone holes in a development program would probably result in a temperature profile comparable to the T63-A-5A baseline combustor.

Visual examination of the combustor after the experiments did not reveal any structural damage and did not indicate any potential durability problem. This was encouraging because no additional film coolant was added. Thus the first coolant film, as shown in Figure 92, had to cool a much larger section of the combustor liner than in the T63-A-5A conventional baseline combustor.

Based upon the significant emissions reduction achieved with the "Extended-Length" liner, its concept was recommended for further study in a conventional-length liner. The concept, as pursued and described in a later section in this appendix, was termed "Delayed Dilution" when applied to the conventional-length liner. If the anticipated low-emission performance is achieved in the conventional envelope, its inclusion in the final low-emission combustor would certainly be recommended.

Further interesting experiments would have been to investigate additional extended lengths. The only extended-length investigated was the 6 inch extension. These additional experiments, supported by the emission kinetics analysis program, would establish the CO, C_xH_y, C versus NO_x trade-offs as a function of intermediate zone resident time. However, these additional studies were beyond the scope of the program.

RICH PRIMARY ZONE COMBUSTOR

The conventional T63-A-5A combustor operates at 0.77 design equivalence ratio in the primary zone at maximum power. Therefore, the conventional combustor has relatively high CO and C_xH_y and low NO_x over the operating range. Task 2 studies and previously reported experimental data had indicated that significant reductions in CO and C_xH_y could be obtained with small increases in NO_x by enriching the primary zone fuel/air ratio.

An available regenerative T63 combustor liner shown in Figure 98 was selected for use in this evaluation of the "Rich Primary Zone"

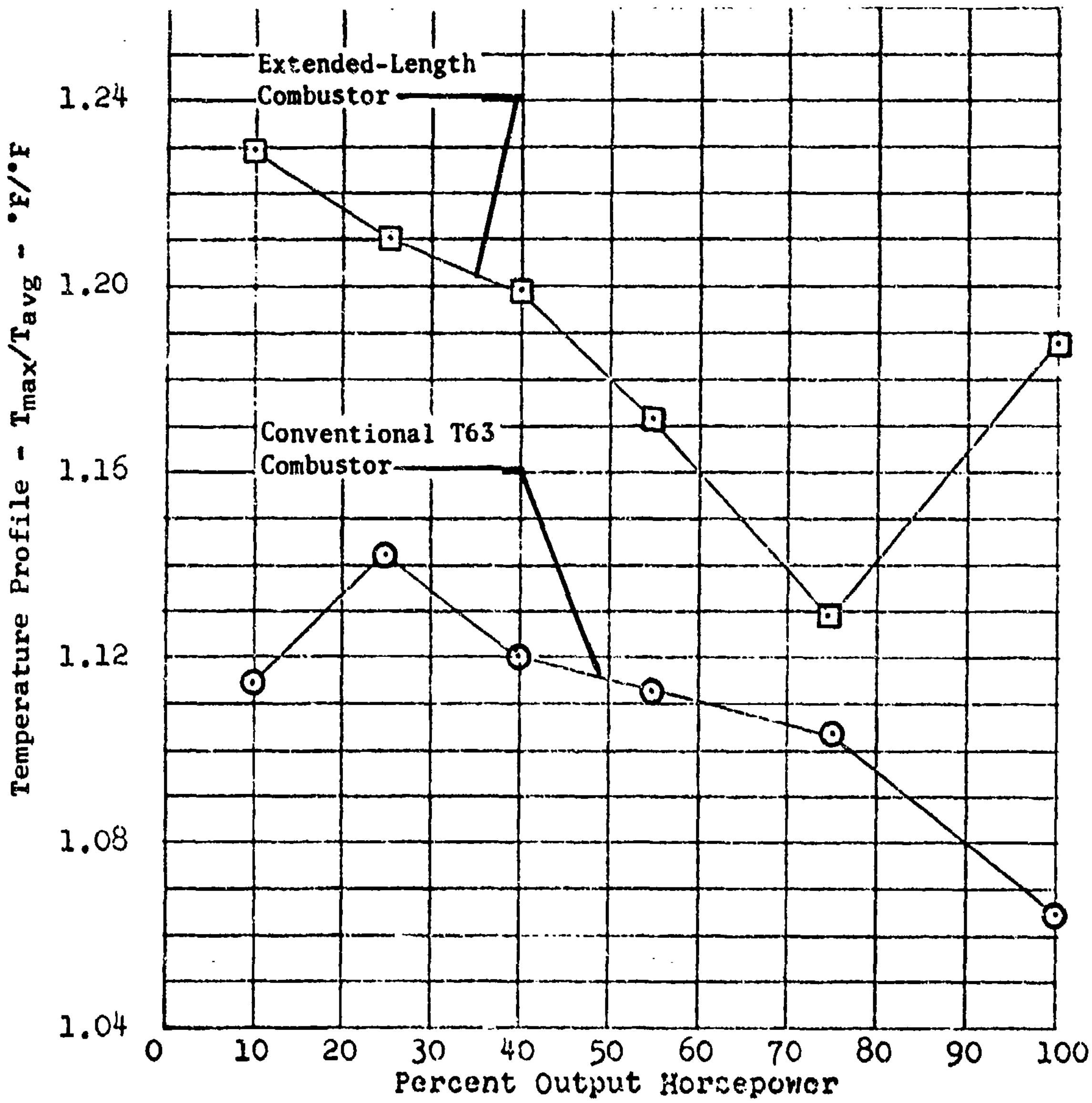


Figure 97. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison With Extended-Length Combustor Liner.

Figure 98. Preliminary Low-Emission Rich-Primary-Zone (Regenerative T63) Combustor Liner.

combustor. The selected combustor was essentially the same as the conventional T63-A-5A combustor except that the holes sizes and number were modified to obtain a 1.0 equivalence ratio in the primary zone at maximum-power, nonregenerative engine conditions.

The rich-primary-zone combustor was tested at the six T63 non-regenerative operating conditions defined in Table IV. These conditions varied from idle (10% power) through maximum power. The combustor was tested with JP-4 fuel. A standard T63 pressure atomizing fuel injector and spark igniter were used in the experiments.

The CO and C_xH_y from the rich-primary-zone combustor were significantly less than from the T63-A-5A conventional combustor, as shown in Figures 99 and 100. However, the NO_x, as shown in Figure 101, increased slightly. The smoke increased considerably, as shown in Figure 102, which was an expected result based upon previous data from other combustors. The emission data presented in Figures 99 through 102 were used to calculate the emission indexes for the previously defined LOH duty cycle. The emission index performance of the rich-primary-zone combustor as compared to the T63-A-5A conventional baseline combustor was as follows:

- The C_xH_y decreased 37%.
- The CO decreased 35%.
- The NO_x increased 10%.
- The particulate increased 221%.

As shown in Table XLVI, the effect on total emissions was a 27% reduction. The contract objective was a reduction in total emissions of 50%. Therefore, the combustor did not meet this objective, nor did it meet the additional objective of no increase in any individual emission. It could, however, be combined with other approaches to perhaps achieve the contract objectives.

AIR-BLAST/AIR-ASSIST FUEL INJECTORS

During this contract, two different air-blast fuel injectors were tested. One of these was also operated as an air-assist fuel injector. For both fuel injectors, the only modifications made to the T63-A-5A conventional liners were changes to the fuel injector bushing so that the particular injector could be used.

The first air-blast fuel injector combustor test was previously designed and developed at DDA for the T63-A-5A engine. However, its emission performance had not been determined previously. This injector was labeled the "DDA Air-Blast Fuel Injector" and is

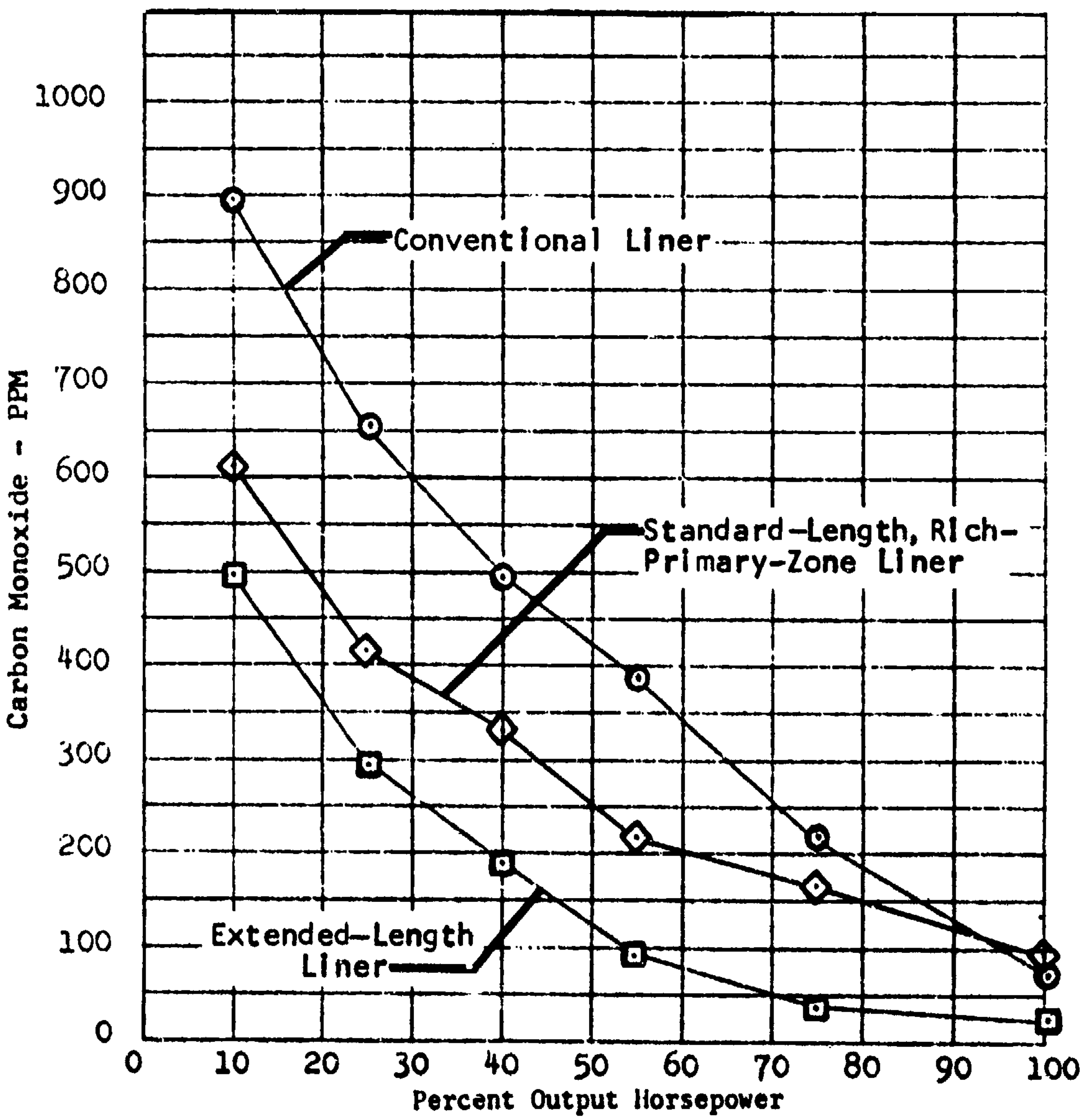


Figure 99. Carbon Monoxide Emission Data Comparison for Standard-Length, Rich-Primary-Zone Combustor (Regenerative T63 Liner), and T63 Baseline Combustors.

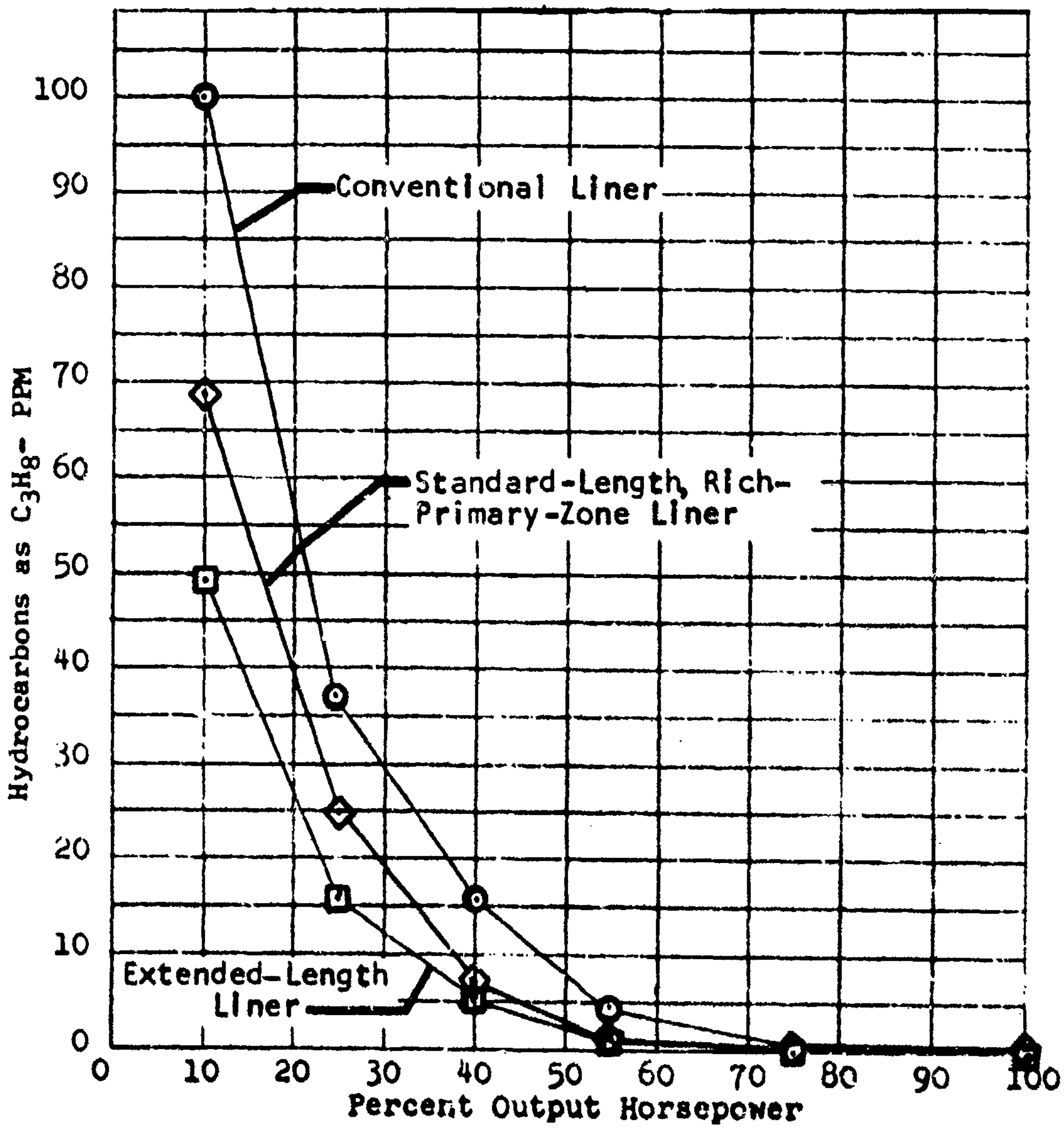


Figure 100. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Standard-Length, Rich-Primary-Zone Combustor (Regenerative T63 Liner), and T63 Baseline Combustors.

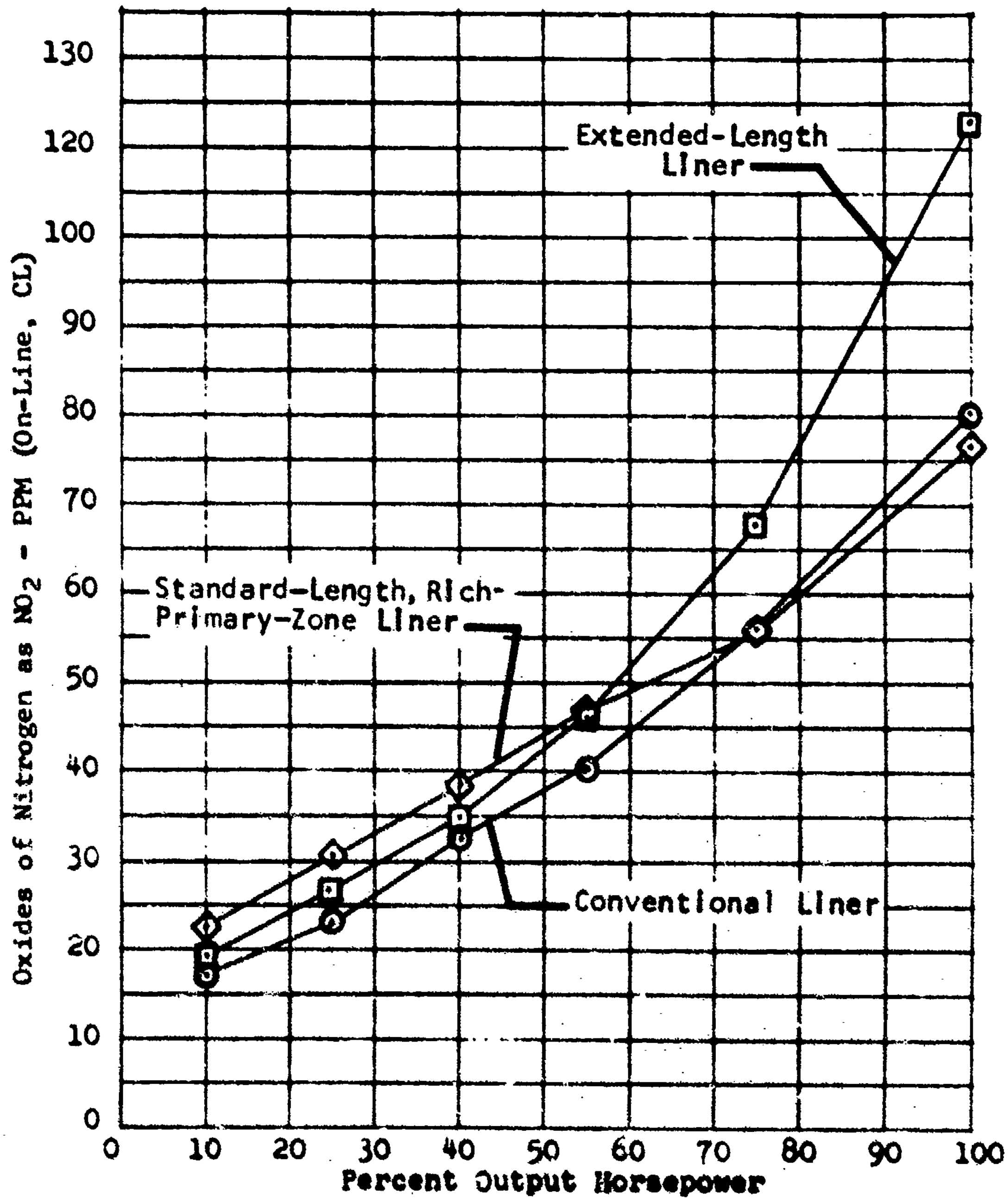


Figure 101. Nonregenerative T63-A-5A Combustor Nitrogen Oxide Emission Data Comparison for Standard-Length, Rich-Primary-Zone Combustor (Regenerative T63 Liner), and T63 Baseline Combustor.

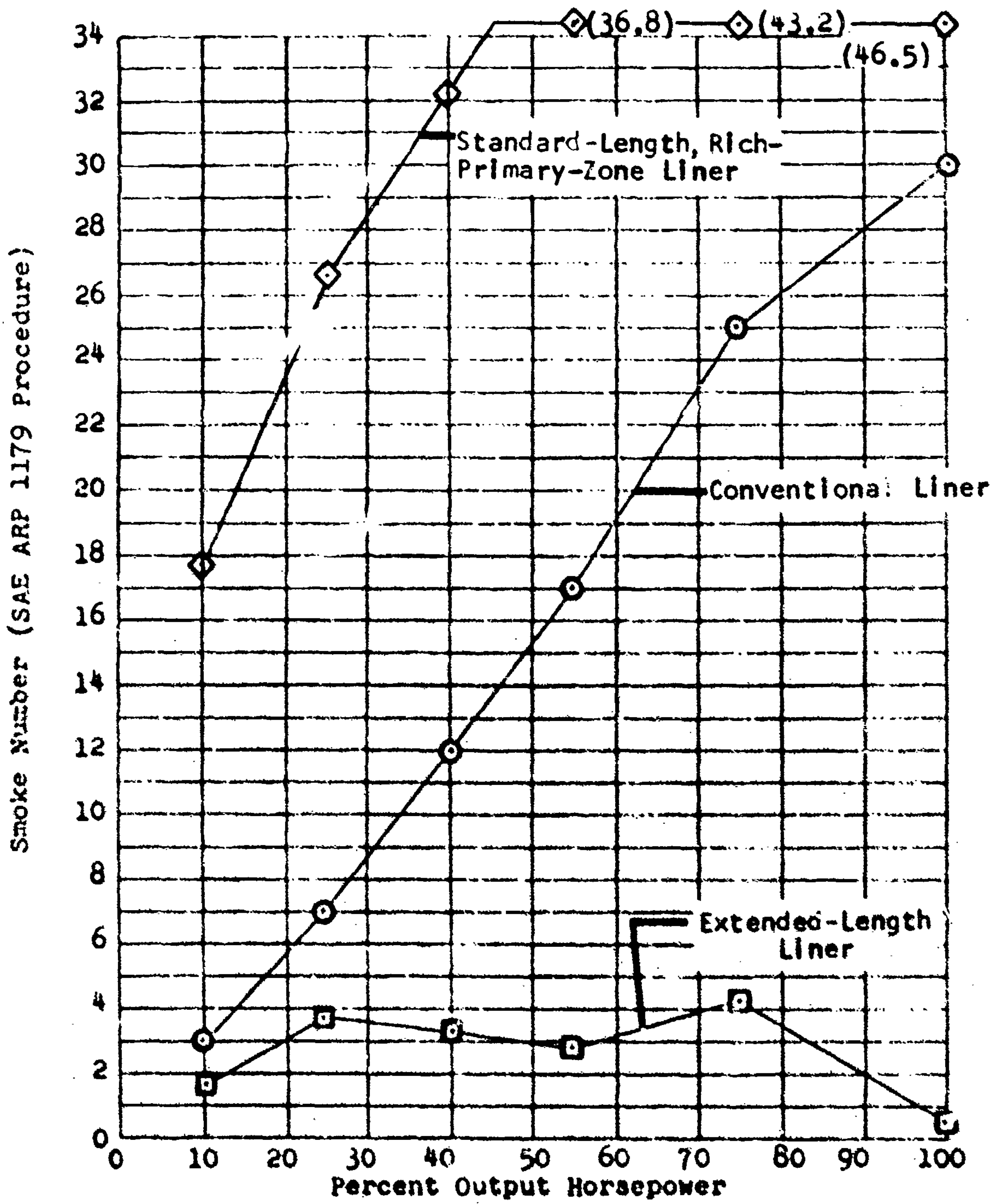


Figure 102. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Standard-Length, Rich-Primary-Zone Combustor (Regenerative T63 Liner), and T63 Baseline Combustors.

pictured as installed in the conventional liner in Figure 103. A view of the installed fuel injector from inside the combustor liner is seen in Figure 104. The DDA air-blast fuel injector utilized a double set of straight bladed radial swirler vanes, which was the primary design difference between the two injectors.

The second fuel injector was manufactured for use on this contract by the Ex-Cell-O Corporation. The Ex-Cell-O fuel injector design sketch is shown in Figure 105. Tangential air passages were cut through the nozzle cylinder surrounding the pressure atomizer. The air-fuel droplet mixture then entered the combustor through the end of the nozzle cylinder. This injector was designed both for a simple air-blast mode (Figure 106), utilizing the differential pressure across the combustor liner as the blast air pressure, and for an air-assist mode (Figure 107), utilizing air from a controlled external air source.

The hole patterns and sizes in the liners were unchanged from their conventional T63 conditions, but because the air was being added through the fuel injectors, the equivalence ratios in the primary decreased an undetermined amount from the 0.77 value in the conventional combustor.

The air-blast/air-assist fuel injectors were tested at the T63 non-regenerative combustor operating conditions given in Table IV. The tests were conducted at steady state conditions using JP-4 fuel and the conventional T63 ignition system.

Air-assist combustor data was obtained for assist pressures of 10% and 20% above burner inlet pressure (BIP) for all combustor conditions for which air-assist supply pressure was adequate.

Carbon monoxide results are presented in Figure 108 and show that the Ex-Cell-O air-blast/air-assist fuel injector produced essentially the same emissions as the conventional combustor except at low-power conditions, where the CO emissions were higher. There was no consistent difference between the air-blast mode and the air-assist mode of this injector in CO emissions. The DDA air-blast fuel injector produced significantly higher CO at all cycle-point conditions. The increases in CO emissions reflect partially the leaning out of the combustor primary zone by the assist or blast air addition.

Considerable increases in hydrocarbon emissions were observed for both nonstandard fuel injectors, as can be seen in Figure 109. Here again, the DDA air-blast injector C_xH_y production was consistently higher (for any mode of operation) than the Ex-Cell-O fuel injector. The air addition by the DDA air-blast injector was much higher than the air addition through the air-blast/air-assist fuel injector, which reduced the primary-zone fuel/air to

Figure 103. External View of DDA Air-Blast Fuel Injector Installed in a Conventional T63-A-5A Combustor Liner.

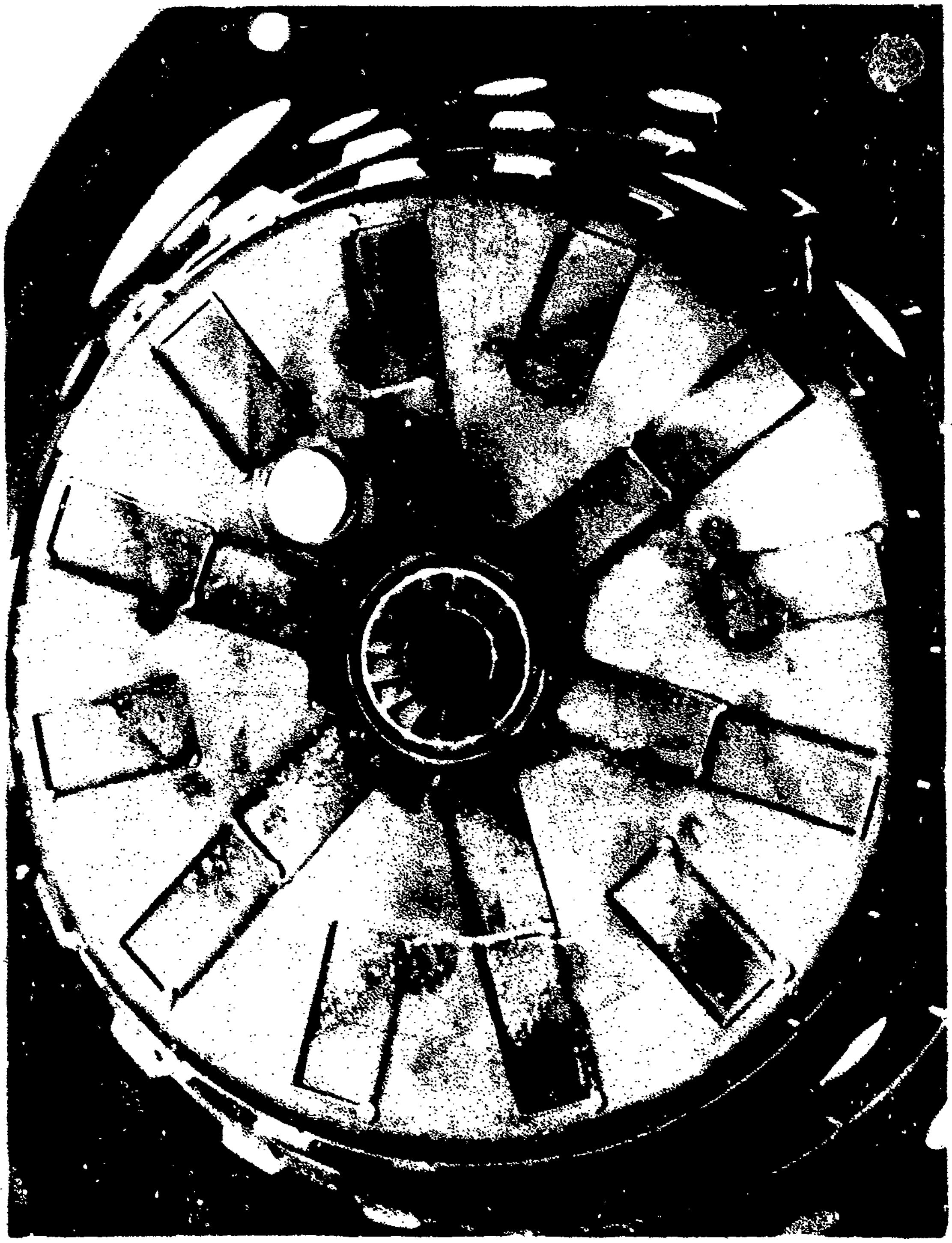
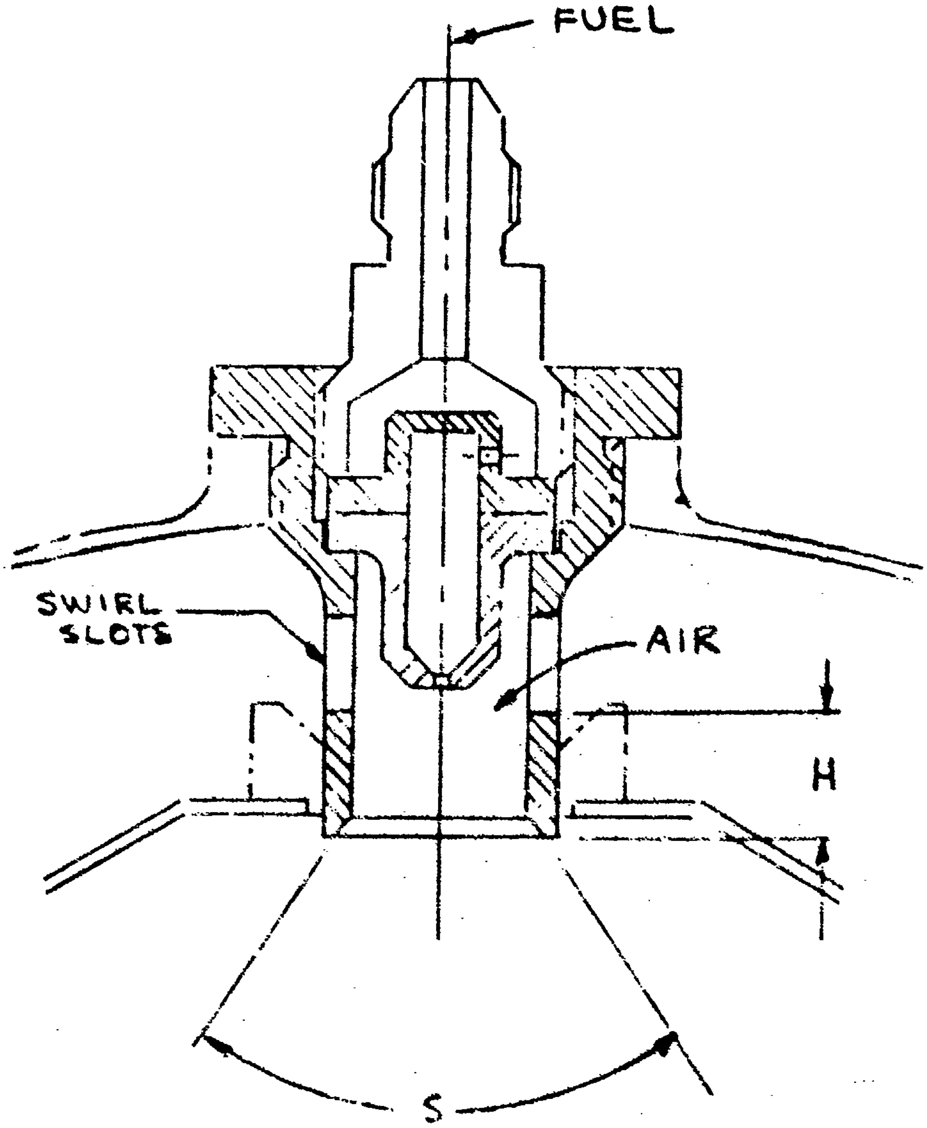


Figure 104. Internal View of a DDA Air-Blast Fuel Injector Installed in a Conventional T63-A-5A Combustor Liner.



Note: Spray Angle "S" Adjustable by Varying Height "H".

Figure 105. Ex-Cell-O Air-Blast/Air-Assist Fuel Injector Design Sketch.

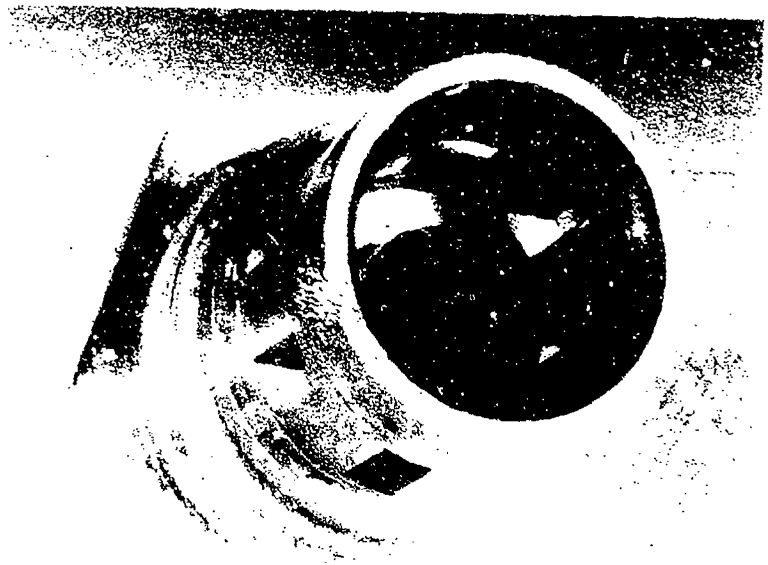


Figure 106. Ex-Cell-O Air-Blast/Air-Assist Fuel Injector - Air-Blast Mode.

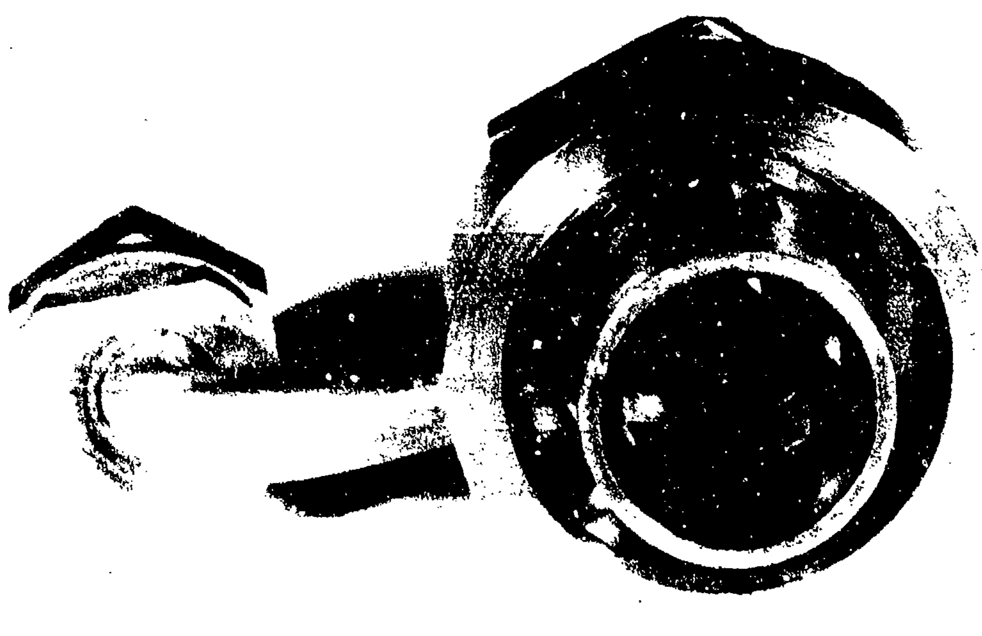


Figure 107. Ex-Cell-O Air-Blast/Air-Assist Fuel Injector - Air-Assist Mode.

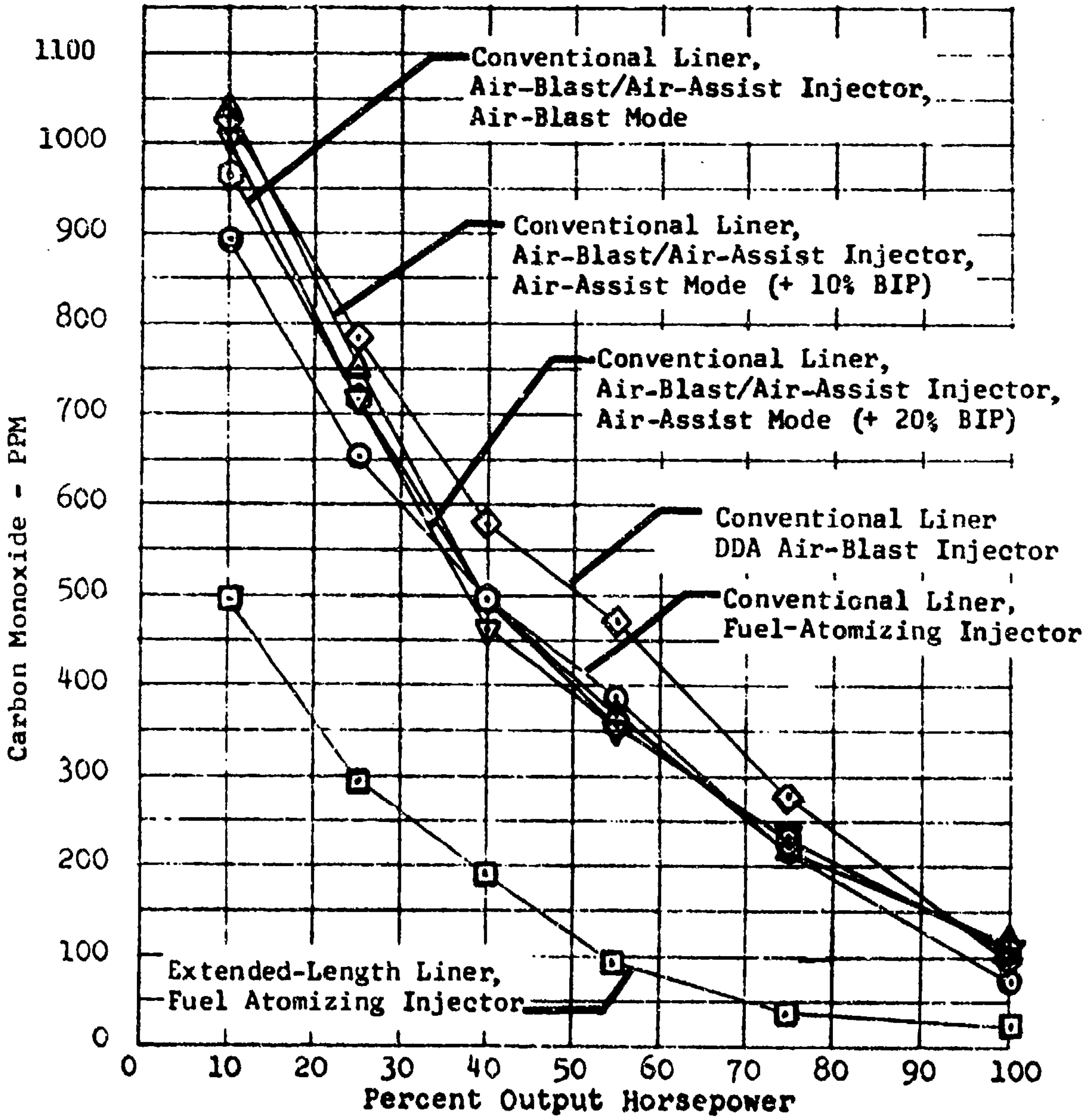


Figure 108. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data for Air-Blast and Air-Assist Fuel Injectors and Baseline Injectors.

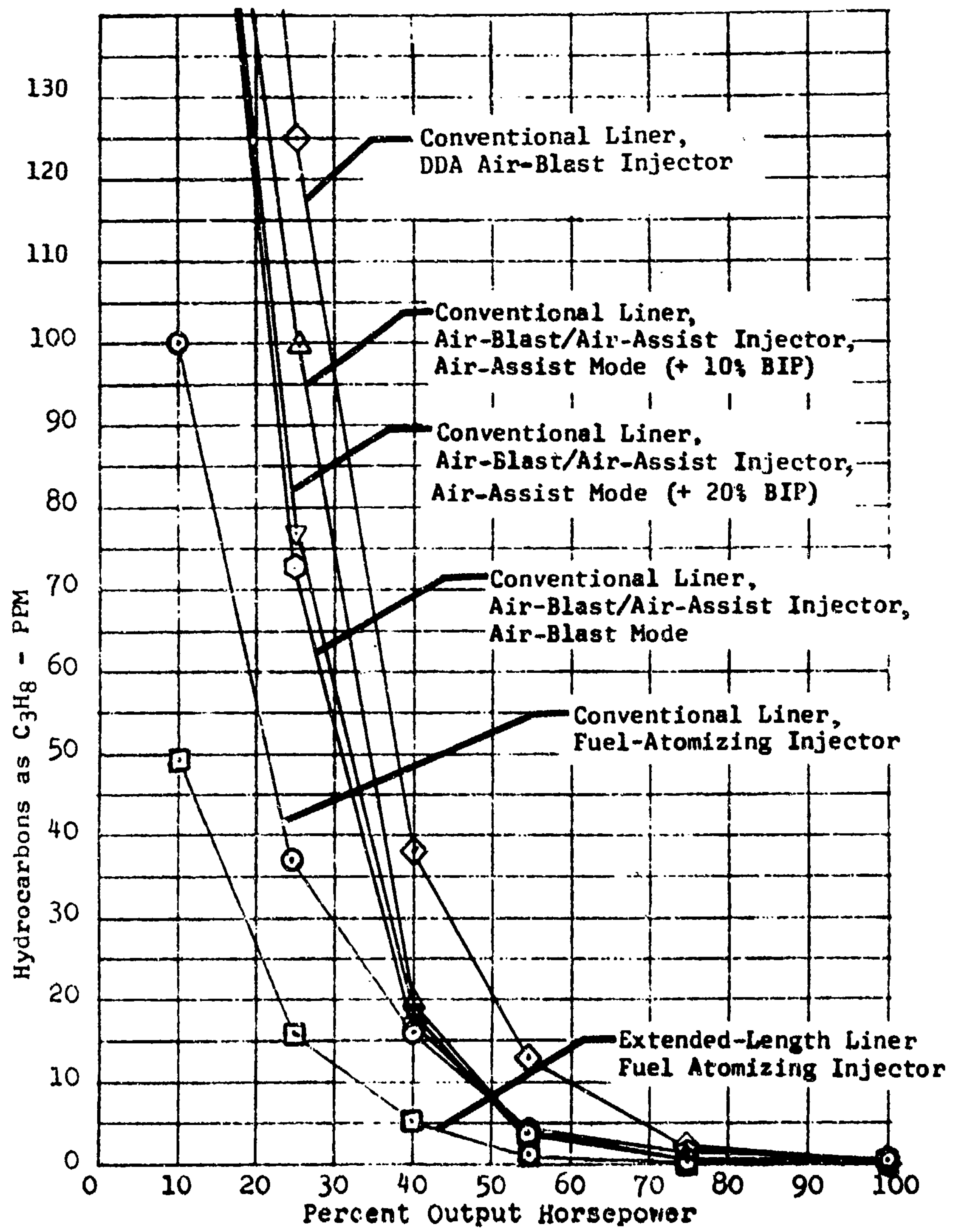


Figure 109. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data for Air-Blast and Air-Assist Fuel Injectors and Baseline Injectors.

the lowest of any of the configurations shown.

Oxides of nitrogen for all configurations, shown in Figure 110, had consistently lower concentrations than the conventional T63 combustor. Of the special fuel injectors, the air assist exhibited lower NO_x on the on-line instruments (NDIR + NDUV); but from the wet chemistry samples (Saltzman), the concentrations were nearly identical.

The greatest variation in the performance of the individual fuel injectors was in the degree of the smoke/particulate reduction from the conventional T63 combustor, see Figure 111. The two air-blast injectors reduced the smoke most significantly. The DDA air-blast injector was as effective in smoke reduction as the 6-inch additional length of the "Extended-Length Liner." The air-assist fuel injection exhibited adequate smoke reduction above 50% power operating conditions. Since smoke reduction is one of the primary purposes of an air-blast or air-assist fuel injector, all of the data taken showed that the smoke reductions for each injector were good-to-excellent.

The temperature profile data, compared in Figure 112, show T_{max}/T_{avg} values for the air-blast/air-assist fuel injectors somewhere between the "Conventional T63 Combustor" and the "Extended-Length Combustor." The DDA air-blast fuel injector exhibited temperature profiles equal to the "Conventional T63 Combustor."

Using the data presented in Table XLVII, the Emission Index (EI) values for the selected LOH duty cycle were calculated. The results of those calculations are summarized below:

Fuel Injector	Emission Index lb emission/1000 lb fuel
DDA Air Blast	40.440
Ex-Cell-O	
Air Blast	33.128
10% Air Assist	33.946
20% Air Assist (No data for 75% and 100% power)	27.127

The EI for the "Conventional T63 Combustor" with the standard pressure-atomizing fuel injector was 32.946 lb emission/1000 lb fuel. The Ex-Cell-O air-blast/air-assist fuel injector showed almost no increase in total EI because the increase in C_xH_y was offset by the reductions in NO_x and smoke. However, the DDA air-blast injector test revealed an increase in total emissions of 23%

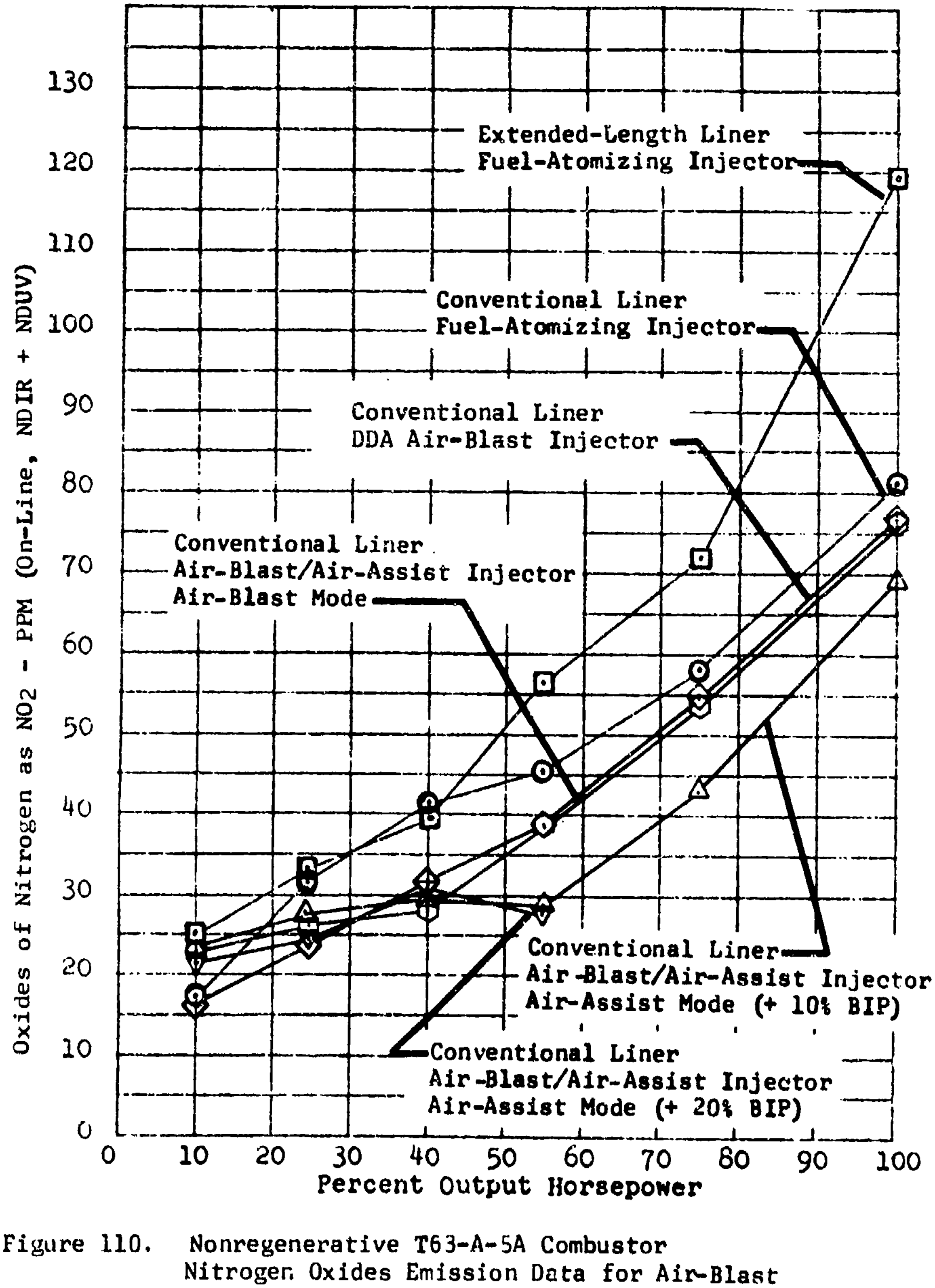


Figure 110. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data for Air-Blast and Air-Assist Fuel Injectors and Baseline Injectors.

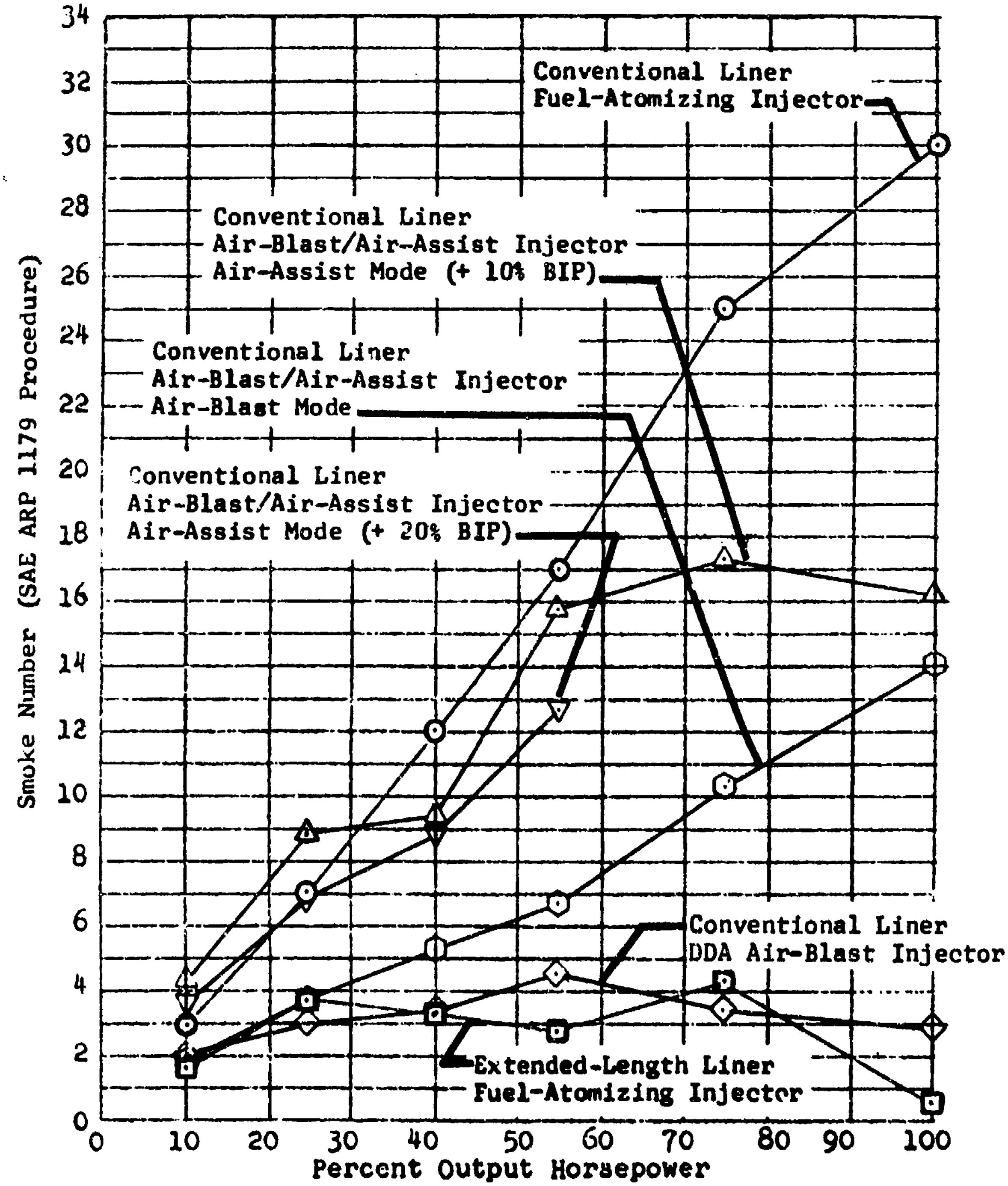


Figure 111. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Air-Blast and Air-Assist Fuel Injectors and Baseline Injectors.

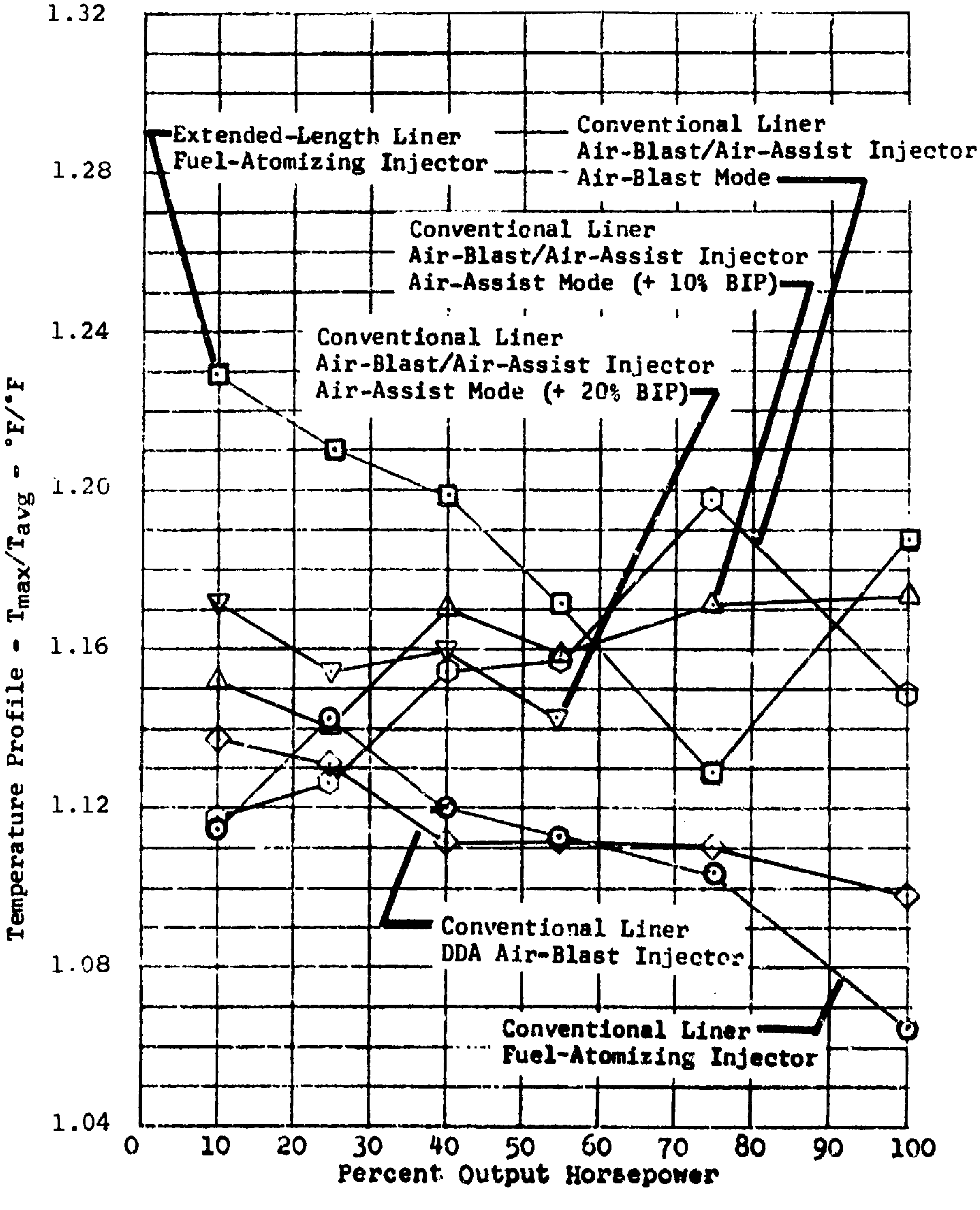


Figure 112. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Air-Blast and Air-Assist Fuel Injectors and Baseline Injectors.

TABLE XLVII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER WITH STANDARD AIR-ATOMIZING FUEL INJECTOR, (2) EXTENDED-LENGTH LINER WITH STANDARD FUEL INJECTOR, (3) CONVENTIONAL LINER WITH DDA AIR-BLAST FUEL INJECTOR, (4) CONVENTIONAL LINER WITH AIR-BLAST/AIR-ASSIST FUEL INJECTOR IN AIR-BLAST MODE, (5) CONVENTIONAL LINER WITH AIR-BLAST/AIR-ASSIST FUEL INJECTOR IN AIR-ASSIST MODE (+ 10% ΔP ABOVE BIP), (6) CONVENTIONAL LINER WITH AIR-BLAST/AIR-ASSIST FUEL INJECTOR IN AIR-ASSIST MODE (+ 20% ΔP ABOVE BIP)

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Standard Length DDA Air Blast Injector						
A. Emissions						
CO, (ppm)	1031.0	786.1	581.1	470.2	275.9	99.3
H/C, (ppm)	282.5	125.0	38.0	13.0	2.1	0.2
NO_x, (On-Line, CL) (ppm)	16.9	24.1	32.1	38.7	54.8	76.8
Smoke Number	2.05	3.0	3.4	4.6	3.46	2.95
B. Pressure Loss (%)	4.67	4.49	4.66	4.44	4.57	4.36
C. Temp. Profile (T_{max}/T_{avg})	1.138	1.131	1.118	1.117	1.102	1.099

Table XLVII - Continued	Cycle Point					
	1	6	5	4	3	2
IV. Standard Length Air-Blast/Air-Assist Injector in Air-Blast Mode						
A. Emissions						
CO, (ppm)	966.5	717.8	495.0	359.2	228.1	108.6
H/C, (ppm)	175.0	73.0	16.5	4.2	1.6	.5
NO_x, (On-Line, NDIR & NDUV) (ppm)	23.0	26.0	28.0	38.5	53.5	76.0
NO_x, (Saltzman) (ppm)	16.5	22.6	31.9	41.3	55.3	81.2
Smoke Number	1.93	3.77	5.23	6.75	10.31	14.02
B. Pressure Loss (%)	5.47	5.35	5.52	5.24	5.15	4.58
C. Temp. Profile (T_{max}/T_{avg})	1.117	1.127	1.155	1.158	1.198	1.149
V. Standard Length Air-Blast/Air-Assist Injector in Air-Assist Mode (10% ΔP)						
A. Emissions						
CO, (ppm)	1042.5	751.7	495.0	362.5	221.0	112.4*
H/C, (ppm)	260.0	99.0	19.0	4.0	.8	.6*
NO_x, (On-Line, NDIR & NDUV) (ppm)	23.5	27.5	29.5	29.0	43.0	69.0*
NO_x, (Saltzman) (ppm)	15.2	23.2	30.9	41.4	55.5	89.7*
Smoke Number	4.32	8.93	9.48	15.80	17.33	16.18*
B. Pressure Loss (%)	5.37	5.37	5.57	5.39	5.02	4.72*
C. Temp. Profile (T_{max}/T_{avg})	1.152	1.141	1.170	1.159	1.171	1.174*
VI. Standard Length Air-Blast/Air-Assist Injector in Air-Assist Mode (20% ΔP)						
A. Emissions						
CO, (ppm)	1004.2	717.8	465.2	355.9	NO DATA TAKEN	NO DATA TAKEN
H/C, (ppm)	200.0	77.0	18.0	3.2		
NO_x, (On-Line, NDIR & NDUV) (ppm	22.0	24.5	31.0	28.0		
NO_x, (Saltzman) (ppm)	16.4	24.3	33.1	39.8		
Smoke Number	3.71	6.90	8.91	12.78		
B. Pressure Loss (%)	5.35	5.31	5.45	5.26		
C. Temp. Profile (T_{max}/T_{avg})	1.172	1.155	1.160	1.143		

***4.5% ΔP (Maximum Available) Air Assist**

caused by the rise in the CO and C_xH_y concentrations.

In a separate DDA funded test series in 1971, it was experimentally shown that by reducing the primary-zone airflow by partially blocking the dome and primary-zone holes to compensate for the air entering through the injector, the emissions of C_xH_y, CO, and NO_x could be maintained at essentially conventional concentrations (no increase in total EI). The total emissions, as shown in Table XLVI, increased only 6% with the modified liner. The substantial smoke reduction, as seen in Figure 111, was not affected by these liner modifications.

The air-blast/air-assist fuel injector did not reduce the total emissions and thus did not meet the contract objective of a 50% reduction in total emissions. The intent of these tests was to experimentally evaluate the effects of air-blast and air-assist fuel injectors on emissions in general and on smoke in particular. As shown in Table XLVI, the smoke (particulates) was reduced as follows:

- DDA Air-Blast Fuel Injector - 85% reduction
- Ex-Cell-O Air-Blast Fuel Injector - 64% reduction
- Ex-Cell-O Air-Assist Fuel Injector - 26% reduction

This feature of smoke reduction with no significant effect on other emissions can have immediate application in combustors which require smoke control.

Visual examination of the combustor liners and fuel injectors after the test did <u>not</u> reveal any apparent damages.

It was recommended that an air-blast fuel injector be used in the final combustor concept.

VARIABLE-GEOMETRY COMBUSTOR

The modifications made to the T63 conventional liner to obtain a "Variable-Geometry, Extended-Length Liner," as shown in Figure 113, were:

- Add 6 inch length, of constant diameter, aft of the primary holes.
- Close the trim and dilution holes in the conventional liner.
- Add six rectangular dilution holes (1.621 x 1.460 circular arc on O.D.), equally spaced.
- Add a variable-geometry slip band over the dilution holes such that the dilution hole open area can be adjusted at any position from full open to full closed. The variable-geometry band movement was in the circumferential direction.

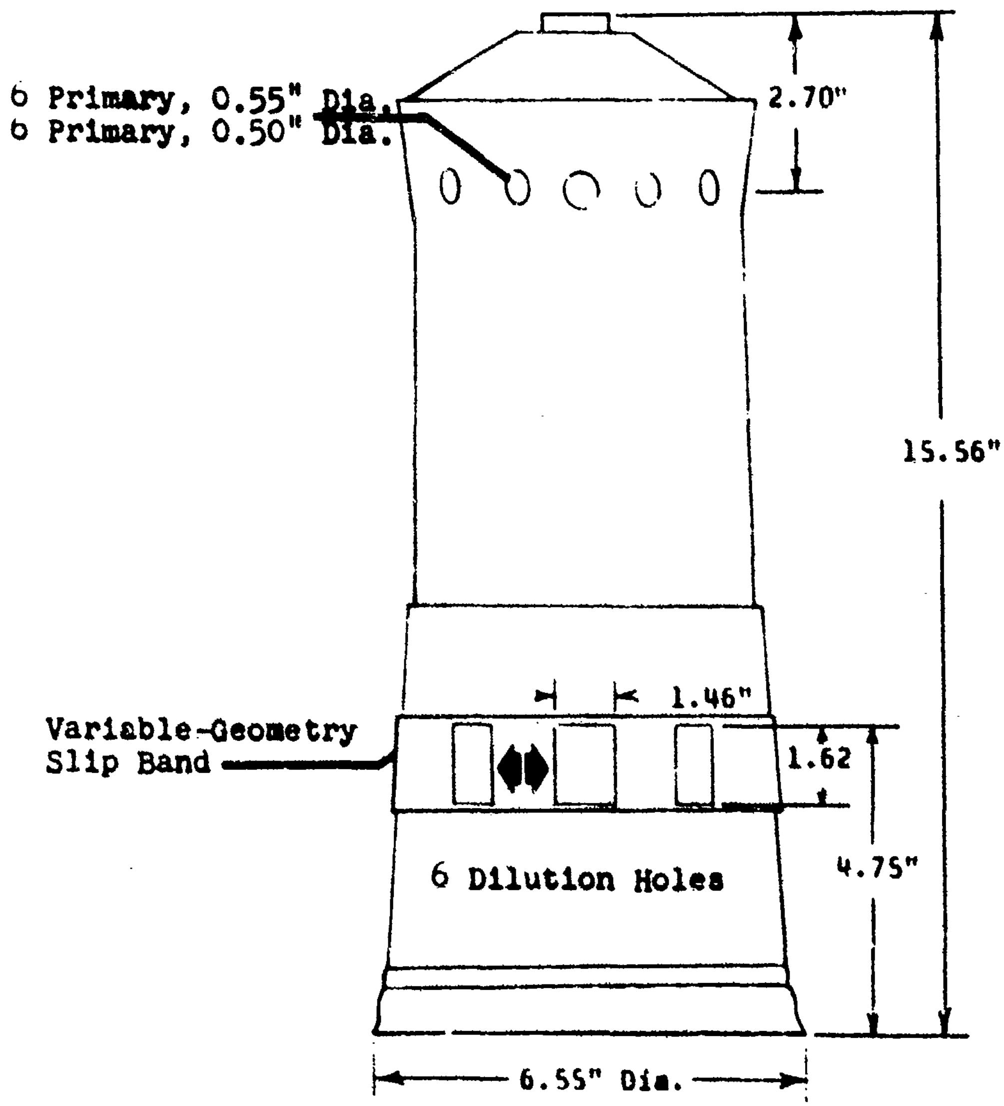


Figure 113. Preliminary Low-Emission, Variable-Geometry, Extended-Length Combustor Liner.

With the above geometry modifications, the "Variable-Geometry, Extended-Length Liner" could operate over the following range of calculated primary-zone equivalence ratios:

Dilution Zone Variable Geometry Setting	Primary Zone Equivalence Ratio (@ max. power)
100% Open	1.54
80% Open	1.33
60% Open	1.11
40% Open	0.897
20% Open	0.682
0% Open	0.466

The hole pattern and size comparison for the "Variable-Geometry, Extended-Length Liner," "Conventional Liner," and "Extended-Length Liner" is shown in Figure 114. The airflow area splits for the "Conventional Liner" and "Extended-Length Liner" were the same and are tabulated below:

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes.	26.3%
Second Cooling Step.	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above calculated flow splits, the primary zone equivalence ratio at maximum power is 0.77.

The "Variable-Geometry, Extended-Length Liner" as fabricated for test is shown in Figure 115. The liner was tested in the T63 combustor rig at all the nonregenerative T63 combustor conditions tabulated in Table IV and at some of the regenerative T63 combustor conditions tabulated in Table V. JP-4 fuel and the standard T63 pressure-atomizing fuel injector were used in all the experiments.

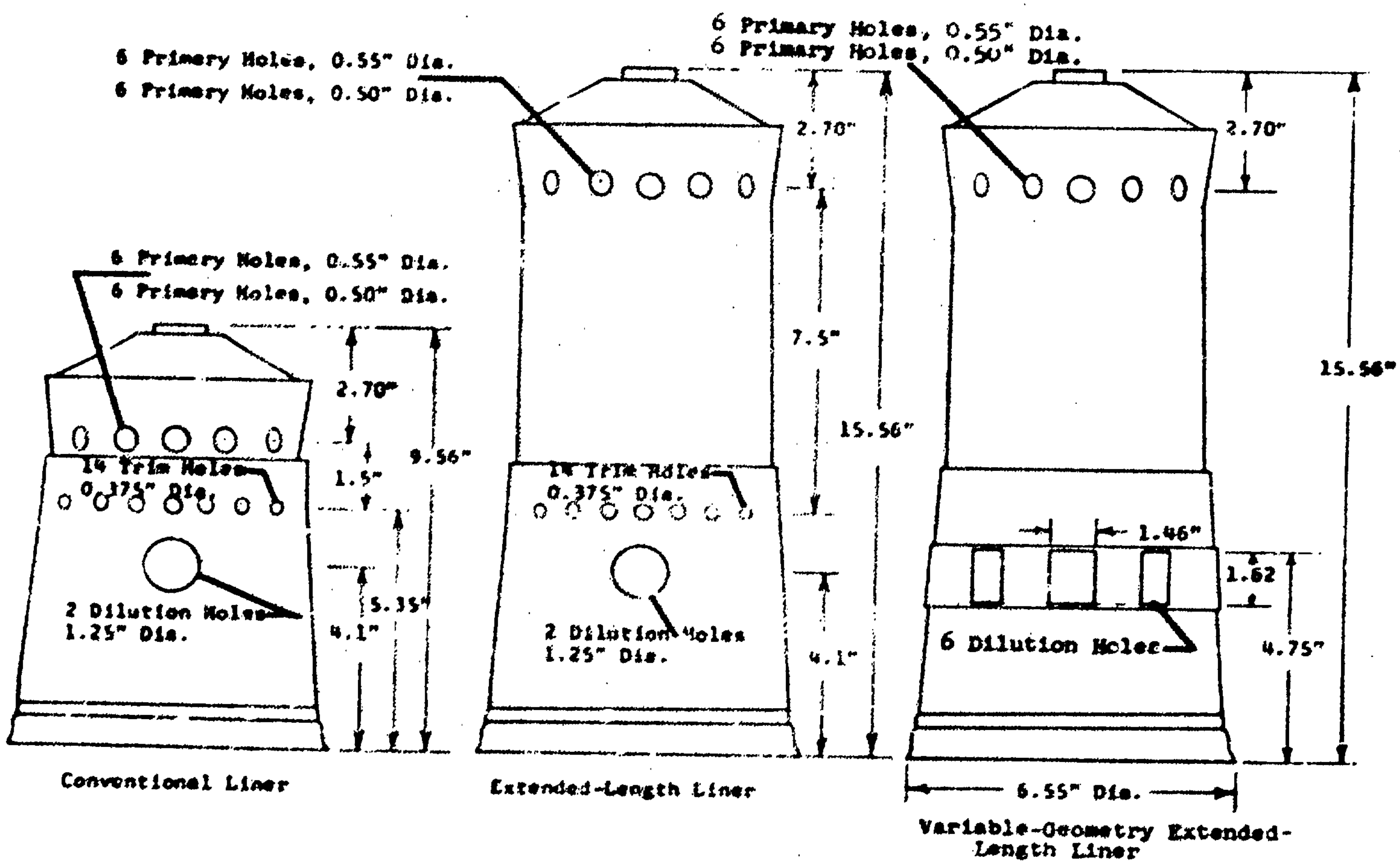


Figure 114. Hole Pattern and Size Comparison of Liners.

Figure 115. Preliminary Low-Emission, Variable-Geometry, Extended-Length Combustor Liner.

The emission data at nonregenerative conditions for the "Variable-Geometry, Extended-Length Liner" is summarized in Table XLVIII. Emission data was obtained with the variable-geometry dilution set at the following open positions: 100%, 80%, 60%, 40%, 20%, and 0%. As shown in Table XIVIII, data was not obtained at all variable-geometry cycle-point combinations. Although more combinations could have been tested there was the limitation of fuel lean blow-out at some variable-geometry cycle-point combinations. The "Variable-Geometry, Extended-Length Liner" emission data (Table XLVIII) has been compared with emission data from the "Conventional Liner" and "Extended-Length Liner" (Table XLIX). The comparisons for carbon monoxide, hydrocarbon, oxides of nitrogen, and smoke are presented in Figures 116 through 119. The results were approximately as predicted, except the reduction in NO_x at the full-closed, maximum-power conditions was less than predicted. This could be a result of air leakage under the variable-geometry band which would result in a higher primary-zone fuel/air ratio (temperature) than desired to obtain the NO_x emission reduction.

Limited experiments were also conducted at T63 regenerative conditions. The emission data are summarized in Table L and show the same trends as the nonregenerative data:

- Carbon monoxide and hydrocarbon decrease and oxides of nitrogen and smoke increase as the primary-zone fuel/air ratio is increased.

- The carbon monoxide is more responsive to primary-zone fuel/air ratio than the oxides of nitrogen.

As previously stated, it was postulated that there was significant air leakage under the variable-geometry band when it was in the closed position. Therefore, the band was removed and the dilution holes were welded shut. This liner was then tested at T63 non-regenerative and regenerative conditions. The emission results are summarized in Table LI. As presented in Figures 120 through 123, the emissions were compared for the following four liners:

- Conventional Liner.

- Extended-Length Liner.

- Variable-Geometry, Extended-Length, Dilution Closed Position.

- Variable-Geometry, Extended-Length, Dilution Welded Shur.

TABLE XLVIII. EMISSION DATA FOR VARIABLE-GEOMETRY, EXTENDED-LENGTH T63 COMBUSTOR AT NONREGENERATIVE CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
DILUTION ZONE VARIABLE GEOMETRY SETTING						
100% Open						
CO (ppm)	225.7					
H/C (ppm)	12.6					
NO_x (ppm)	40.6					
Smoke Index	23.9					
80% Open						
CO (ppm)	216.4					
H/C (ppm)	16.8					
NO_x (ppm)	39.8					
Smoke Index	15.2					
60% Open						
CO (ppm)	209.6	119.9				
H/C (ppm)	16.4	2.3				
NO_x (ppm)	35.7	41.1				
Smoke Index	9.1	5.22				
40% Open						
CO (ppm)	270.6	202.9	104.9			
H/C (ppm)	23.0	9.8	1.3			
NO_x (ppm)	28.1	35.6	48.9			
Smoke Index	0.76	2.65	4.30			
20% Open						
CO (ppm)	-	376.0	237.6	154.7	61.5	
H/C (ppm)	-	17.0	4.0	1.7	1.1	
NO_x (ppm)	-	28.7	40.1	55.1	71.89	
Smoke Index	-	0.88	1.71	5.50	-	
0% Open						
CO (ppm)	-		587.4	349.5	135.2	34.4
H/C (ppm)	-		40.0	8.5	1.5	1.7
NO_x (ppm)	-		33.2	48.0	59.7	90.03
Smoke Index	-		1.20	3.8	4.75	4.26

TABLE XLIX. BASELINE COMBUSTOR PERFORMANCE DATA

	Cycle Point					
	1	6	5	4	3	2
I. Conventional (Nonregenerative) Liner						
A. Nonregenerative Conditions						
1. Emissions						
CO, (ppm)	893.	652.	496	383	214	75
H/C, (ppm)	100.	37.	15.8	4.1	0.7	0.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.0	17.	25.0	30.0
2. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
3. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
B. Regenerative Conditions						
1. Emissions						
CO (ppm)	346.2	242.5	197.2	142.9	85.8	38.0
H/C (CL) (ppm)	8.8	2.6	1.4	1.5	3.3	1.5
NO_x (ppm)	27.0	33.6	39.7	53.8	75.8	102.9
Smoke Number	≈ < 2*	0.83	1.35	2.05	4.5	2.5
2. Pressure Loss (%)	6.50	6.52	7.04	6.85	6.27	6.64
3. Temp. Profile (T_{max}/T_{avg})	1.0765	1.0850	1.0801	1.0634	1.065	1.0505
II. Extended-Length (6-inch) Liner						
A. Nonregenerative Conditions						
1. Emissions						
CO (ppm)	495	298	185.5	94.0	38.6	22.6
H/C (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.70	0.59
2. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
3. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188

*All samples zero except W/A = 6

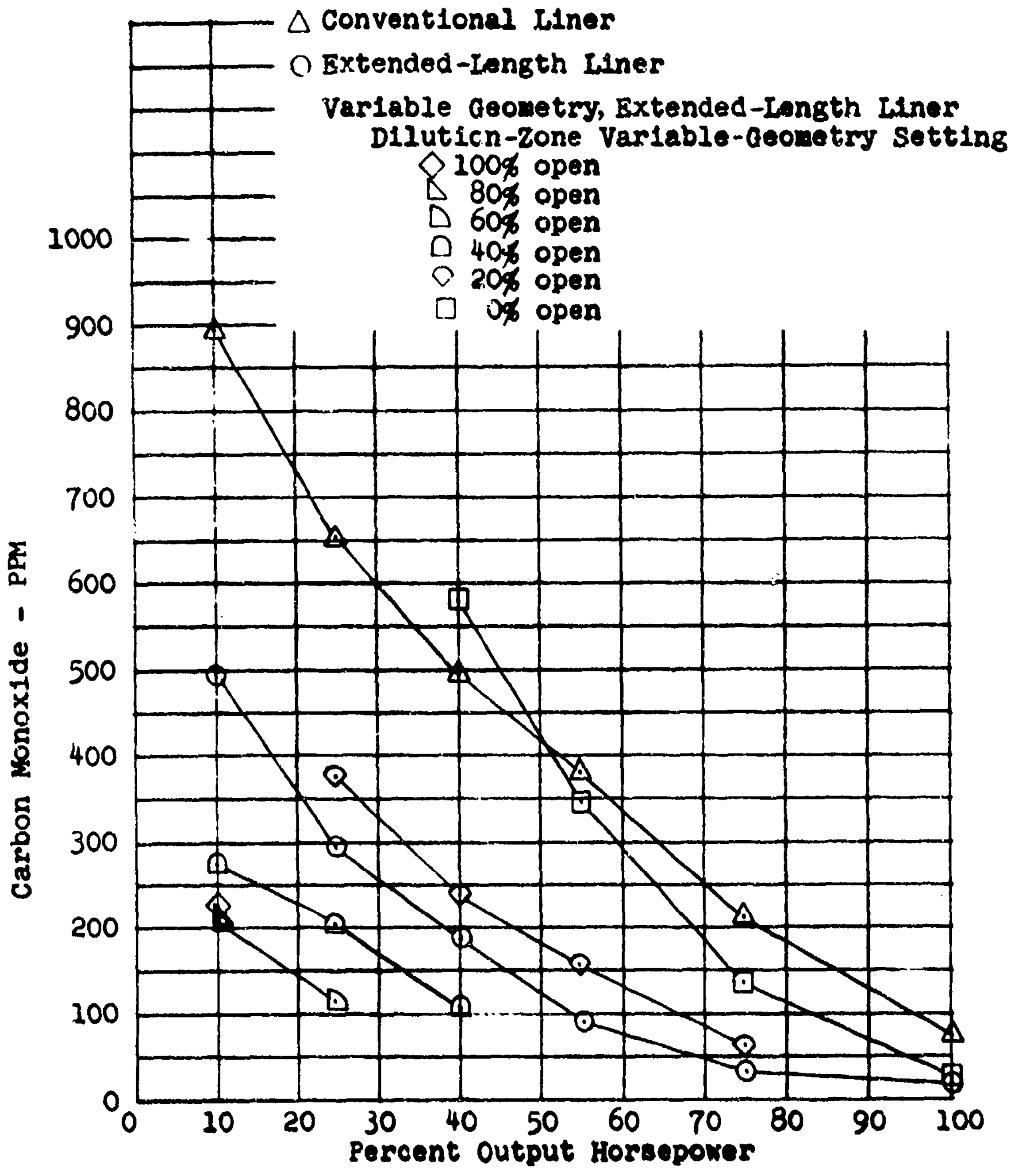


Figure 116. Nonregenerative T63-A-5A Combustor Effect of Variable-Geometry on Carbon Monoxide Emission.

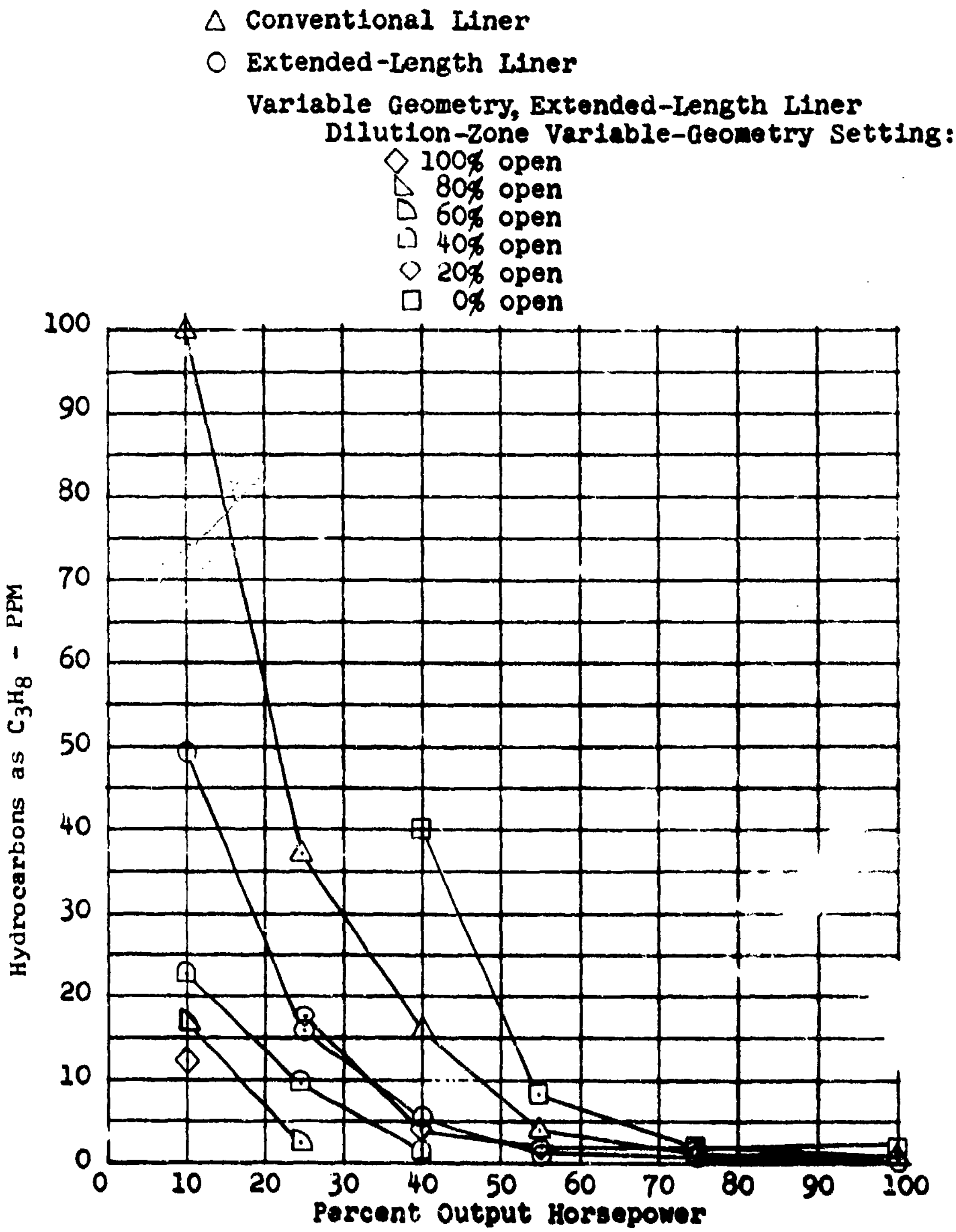


Figure 117. Nonregenerative T63-A-5A Combustor Effect of Variable-Geometry on Hydrocarbon Emission.

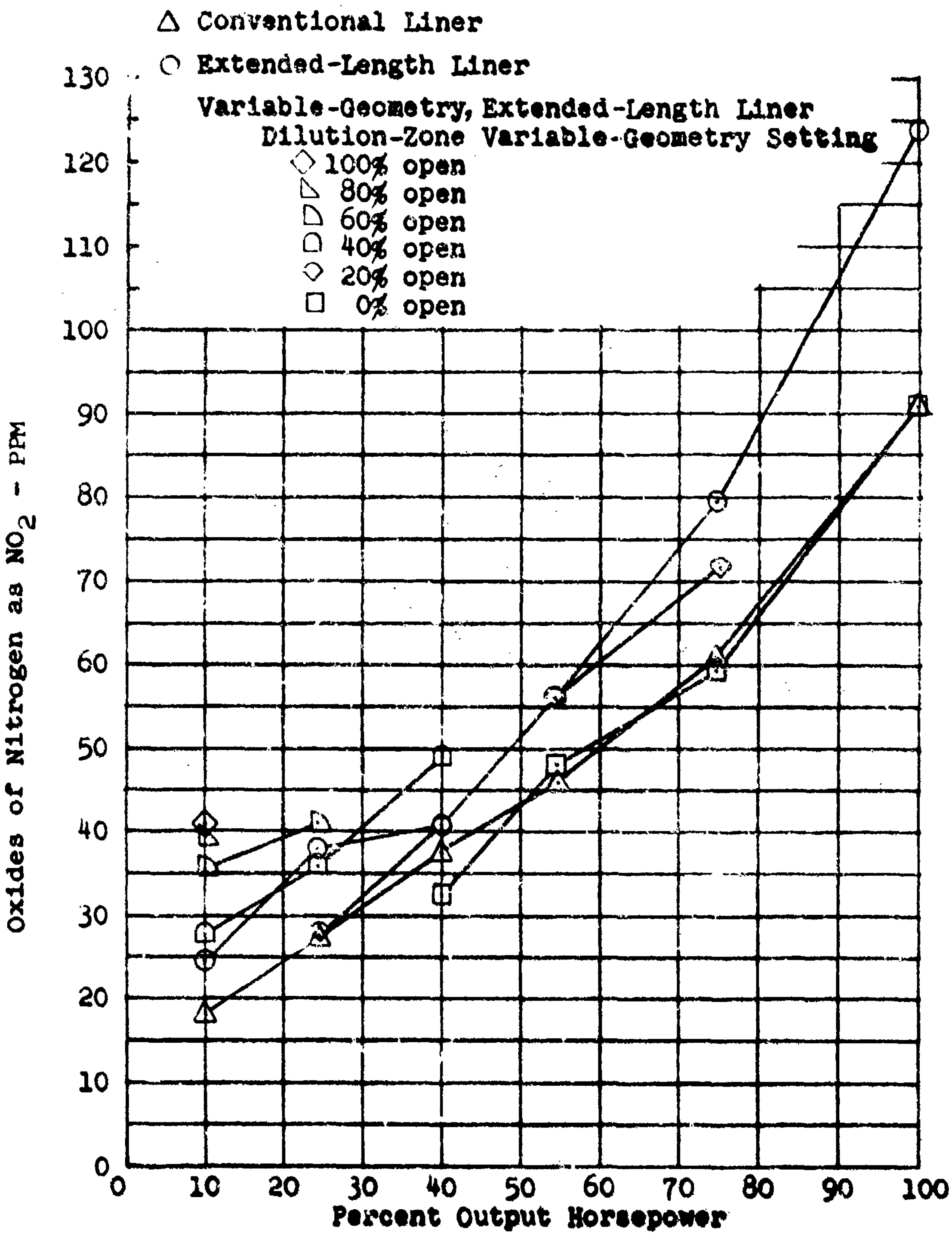


Figure 118. Nonregenerative T63-A-5A Combustor Effect of Variable-Geometry on Nitrogen Oxide Emission.

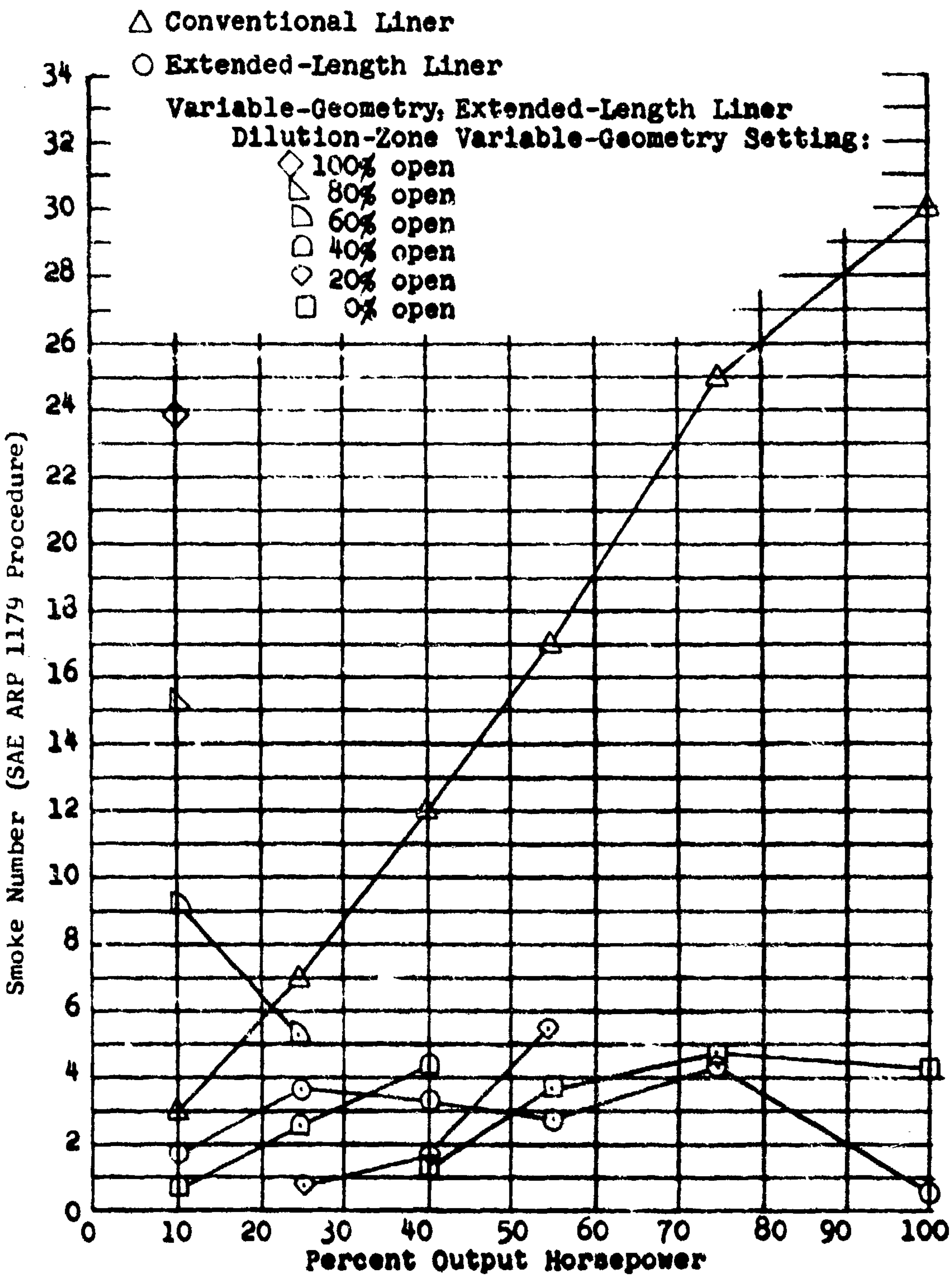


Figure 119. Nonregenerative T63-A-5A Combustor
Effect of Variable Geometry on Smoke Index.

TABLE L. EMISSION DATA FOR VARIABLE-GEOMETRY, EXTENDED-LENGTH T63 COMBUSTOR AT REGENERATIVE CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
DILUTION ZONE VARIABLE						
GEOMETRY SETTING						
40% Open						
CO (ppm)			28.2			
H/C (ppm)			1.2			
NO_x (ppm)			51.21			
Smoke Index			1.60			
20% Open						
CO (ppm)			129.4	68.3		
H/C (ppm)			1.5	1.2		
NO_x (ppm)			42.17	57.06		
Smoke Index			0.41	0		
0% Open						
CO (ppm)			281.3	135.2	51.3	
H/C (ppm)			4.7	1.5	0.5	
NO_x (ppm)			38.52	51.07	72.27	
Smoke Index			0	0	0	

TABLE LI. EMISSION DATA FOR VARIABLE-GEOMETRY, EXTENDED-LENGTH T63 COMBUSTOR-DILUTION HOLES WELDED CLOSED

	Cycle Point					
	1	6	5	4	3	2
I. Nonregenerative Conditions						
CO (ppm)			1081.4	856.6	445.9	116.2
H/C (ppm)			110.0	52.0	7.8	1.0
NO_x (ppm)			22.1	27.4	44.5	65.4
Smoke Index			1.25	1.90	4.70	4.05
II. Regenerative Conditions						
CO (ppm)			495.0	352.7	148.8	34.4
H/C (ppm)			20.0	4.5	0.8	0.6
NO_x (ppm)			24.5	35.2	54.1	93.0*
Smoke Index			0	0.23	0.78	-

*This value adjusted to Saltzman value.

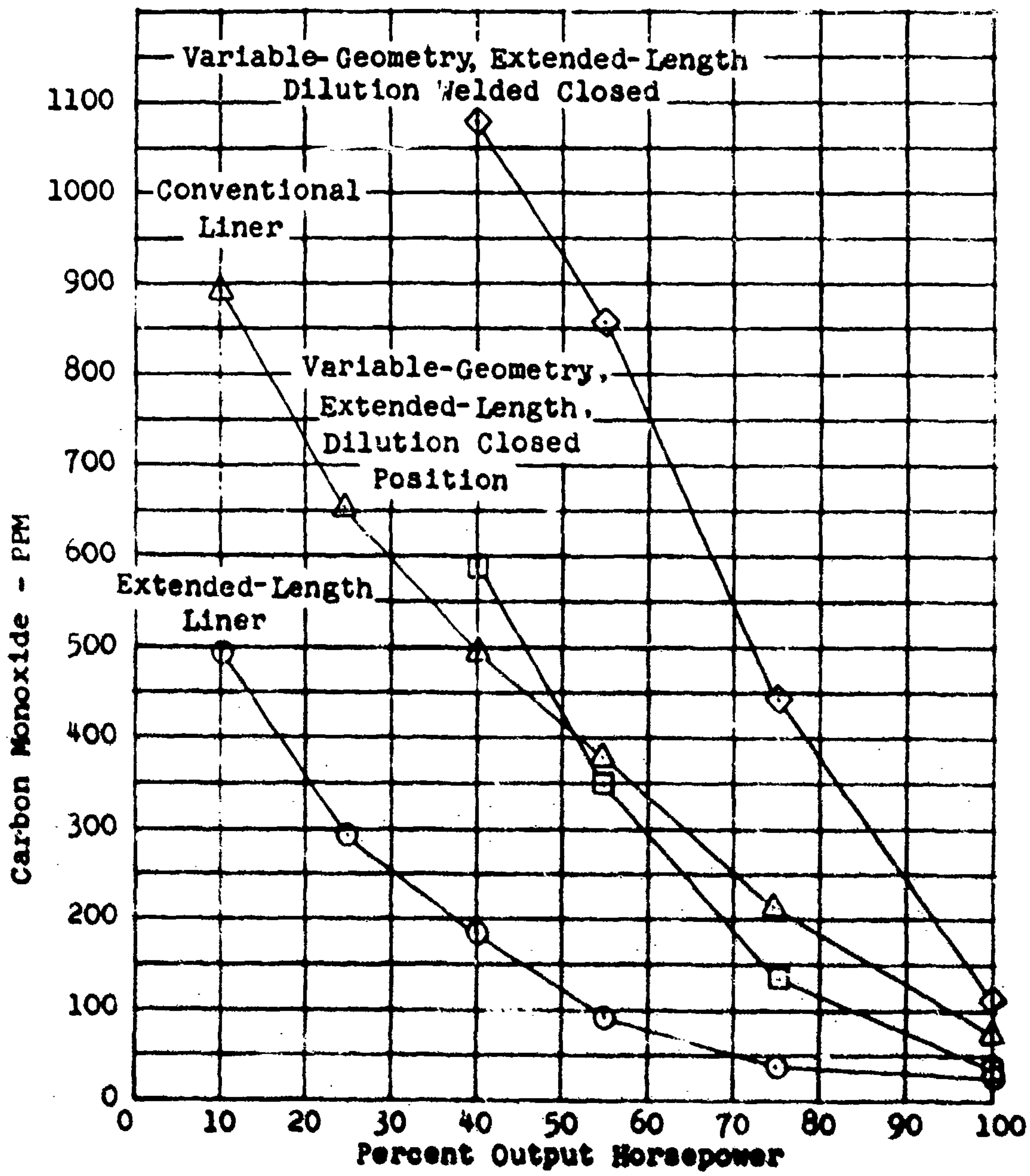


Figure 120. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Combustor for Extended-Length Liner; Variable-Geometry, Extended-Length, Dilution Closed Position; Variable-Geometry, Extended-Length, Dilution Welded Closed; Conventional Liner.

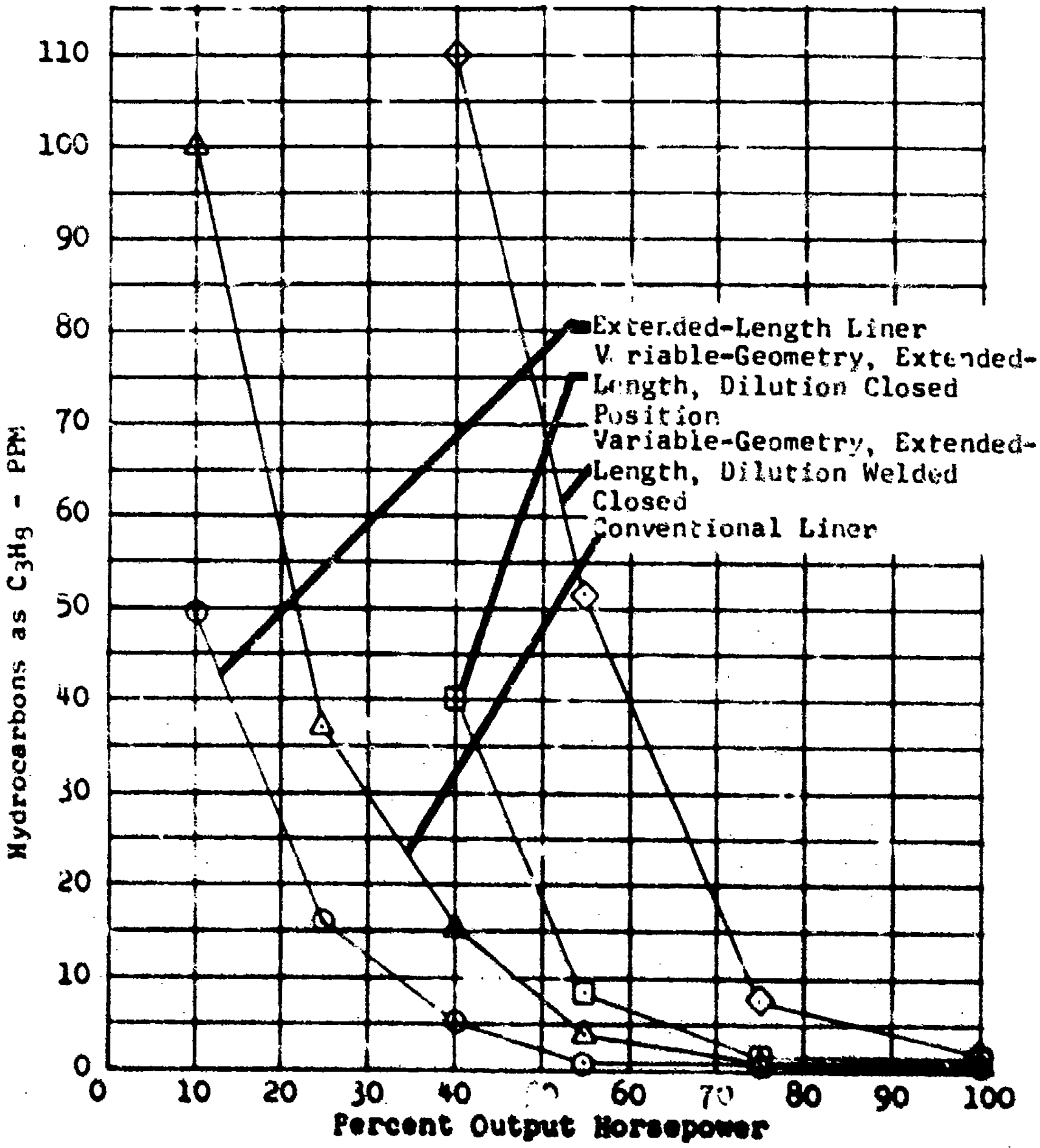


Figure 121. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length Liner; Variable-Geometry, Extended-Length, Dilution Closed Position; Variable-Geometry, Extended-Length, Dilution Welded Closed; and Conventional Liner.

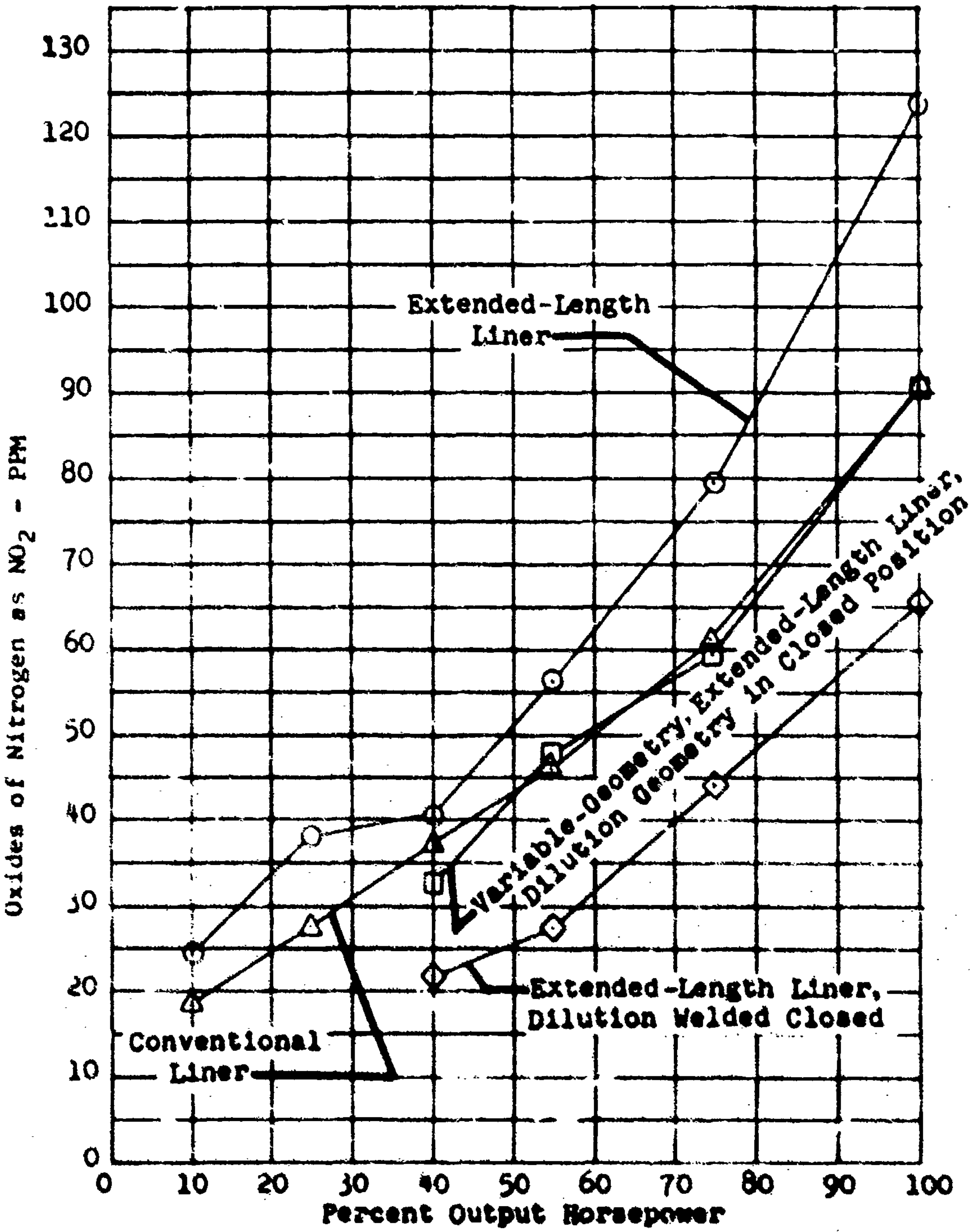


Figure 122. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length Liner; Variable-Geometry, Extended-Length Liner, Dilution Closed; Extended-Length Liner, Dilution Welded Closed; and Conventional Liner.

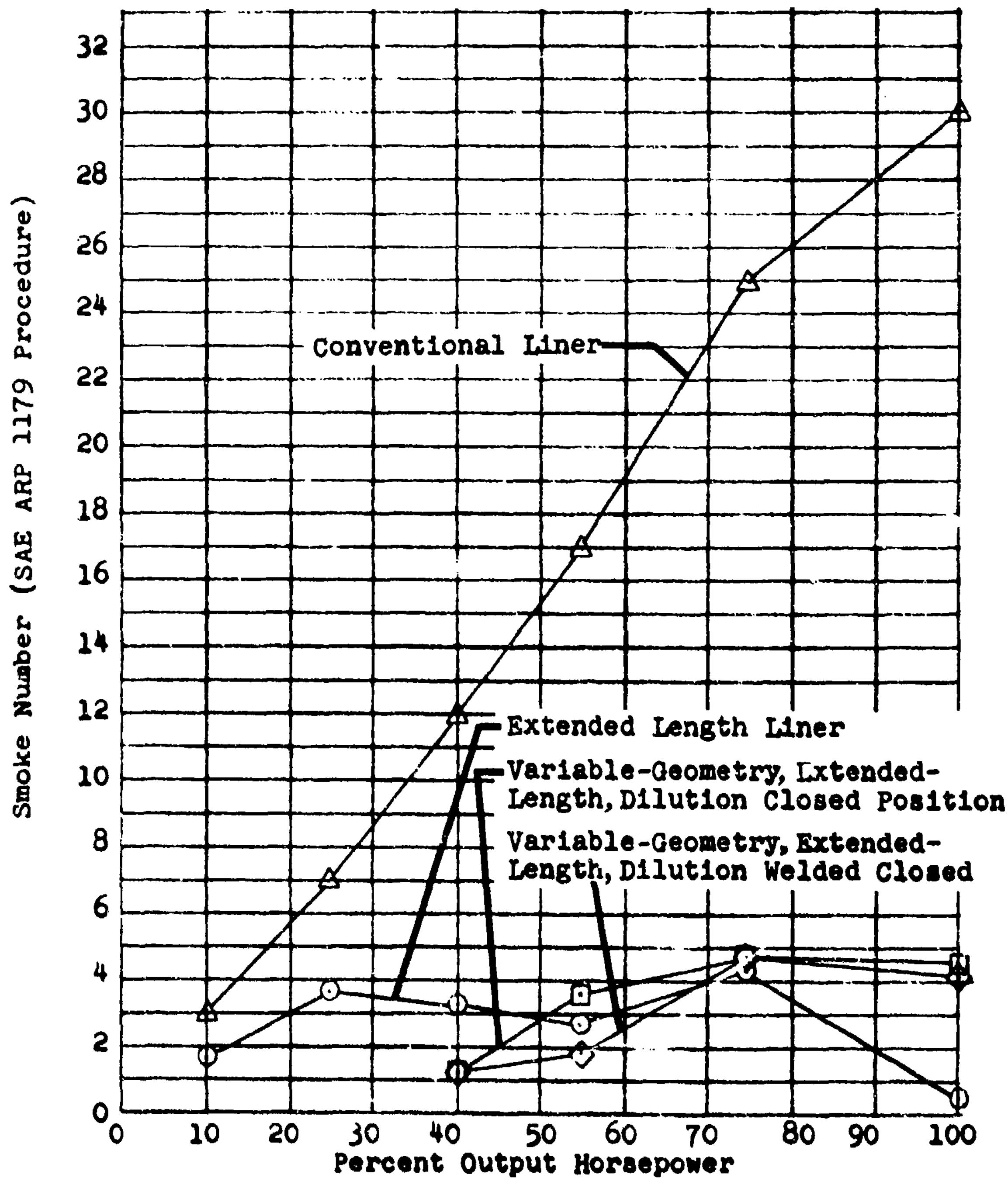


Figure 123. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length Liner; Variable-Geometry, Extended-Length, Dilution Closed Position; Variable-Geometry, Extended-Length, Dilution Welded Closed; and Conventional Liner.

The emission data in Figures 120 through 123 show that there was leakage under the variable-geometry ban-, -! significant differences in the emissions were obtained when the dilution holes were welded shut.

The pressure loss data, summarized in Table LII, shows that the pressure loss increased when the dilution holes were welded shut. This confirms the above conclusion that there was leakage under the dilution band. The pressure loss data in Table LII also leads to the obvious conclusion that if variable geometry is applied in a combustor, both the primary zone and dilution zone must have variable geometry to avoid high pressure loss.

The exhaust temperature profile data is summarized in Table LIII. At most variable-geometry settings, the temperature pattern was better than the "Extended-Length Liner" but worse than the conventional liner.

The emission response (changes in emission with geometry settings) was calculated, and the results are presented in Figures 124 through 127. In general, the CO, H/C, and smoke had a much greater response than the NO_x. For example, as shown in Figure 127, the CO increased by approximately 370% and the NO_x decreased by 50% at maximum power when the dilution hole area was changed from full-open to full-shut positions.

An optimization program, developed in Task 2 studies, was applied to calculate the emission index for the "Variable-Geometry, Extended-Length Liner." The problem was to select the optimum geometry setting to obtain the minimum total emissions. The calculations were made for the following two cases:

- Constrained case - None of the individual emissions (CO, C_xH_y, NO_x, particulates) could increase.
- Unconstrained case - The total emissions were minimized, but individual emissions were allowed to increase if necessary to obtain minimum total emissions.

The optimum geometry settings for minimum emission index for the two cases are summarized as follows:

TABLE LII. COMPARISON OF PRESSURE LOSS (%) FOR VARIABLE-GEOMETRY LINER WITH BASELINE COMBUSTOR LINERS

	Cycle Point					
	1	6	5	4	3	2
I. Variable-Geometry, Extended-Length Liner						
A. Nonregenerative Conditions						
Dilution Zone Variable Geometry Setting						
100% Open	3.14					
80% Open	3.42					
60% Open	3.82	3.99				
40% Open	4.14	4.46	4.57			
20% Open		5.26	5.73	5.81	5.48	
0% Open			7.06	6.68	6.51	6.30
Dilution Welded Close			8.81	9.40	8.79	8.28
B. Regenerative Conditions						
Dilution Zone Variable Geometry Setting						
100% Open						
80% Open						
60% Open						
40% Open			6.26			
20% Open			8.42	8.43		
0% Open			9.90	10.04	9.05	
Dilution Welded Close			13.82	13.64	12.27	12.49
II. Conventional Liner						
A. Nonregenerative Conditions	4.63	4.51	4.53	4.44	4.38	4.14
B. Regenerative Conditions	6.50	6.52	7.04	6.85	6.27	6.64
III. Extended Length Liner						
A. Nonregenerative Conditions	5.10	4.61	5.09	4.91	4.74	4.59

TABLE LIII. COMPARISON OF EXHAUST TEMPERATURE PROFILE (T_{max}/T_{avg}) FOR VARIABLE-GEOMETRY LINER WITH BASELINE COMBUSTOR LINERS

	Cycle Point					
	1	6	5	4	3	2
I. Variable-Geometry Extended-Length Liner						
A. Nonregenerative Conditions						
Dilution Zone Variable						
Geometry Setting						
100% Open	1.2543					
80% Open	1.1821					
60% Open	1.1692	1.1127				
40% Open	1.1189	1.1129	1.1292			
20% Open		1.0883	1.0803	1.0842	1.0579	
0% Open			1.1027	1.1446	1.1396	1.1571
Dilution Welded Close			1.1855	1.1651	1.1814	1.1465
B. Regenerative Conditions						
Dilution Zone Variable						
Geometry Setting						
100% Open						
80% Open						
60% Open						
40% Open			1.0623			
20% Open			1.0803	1.1573		
0% Open			1.1024	1.0702	1.0662	
Dilution Welded Close			1.1172	1.1202	1.1110	1.1117
II. Conventional Liner						
A. Nonregenerative Conditions	1.115	1.142	1.120	1.113	1.104	1.065
B. Regenerative Conditions	1.0765	1.0850	1.0801	1.0634	1.065	1.0505
III. Extended Length Liner						
A. Nonregenerative Conditions	1.229	1.210	1.198	1.171	1.129	1.188

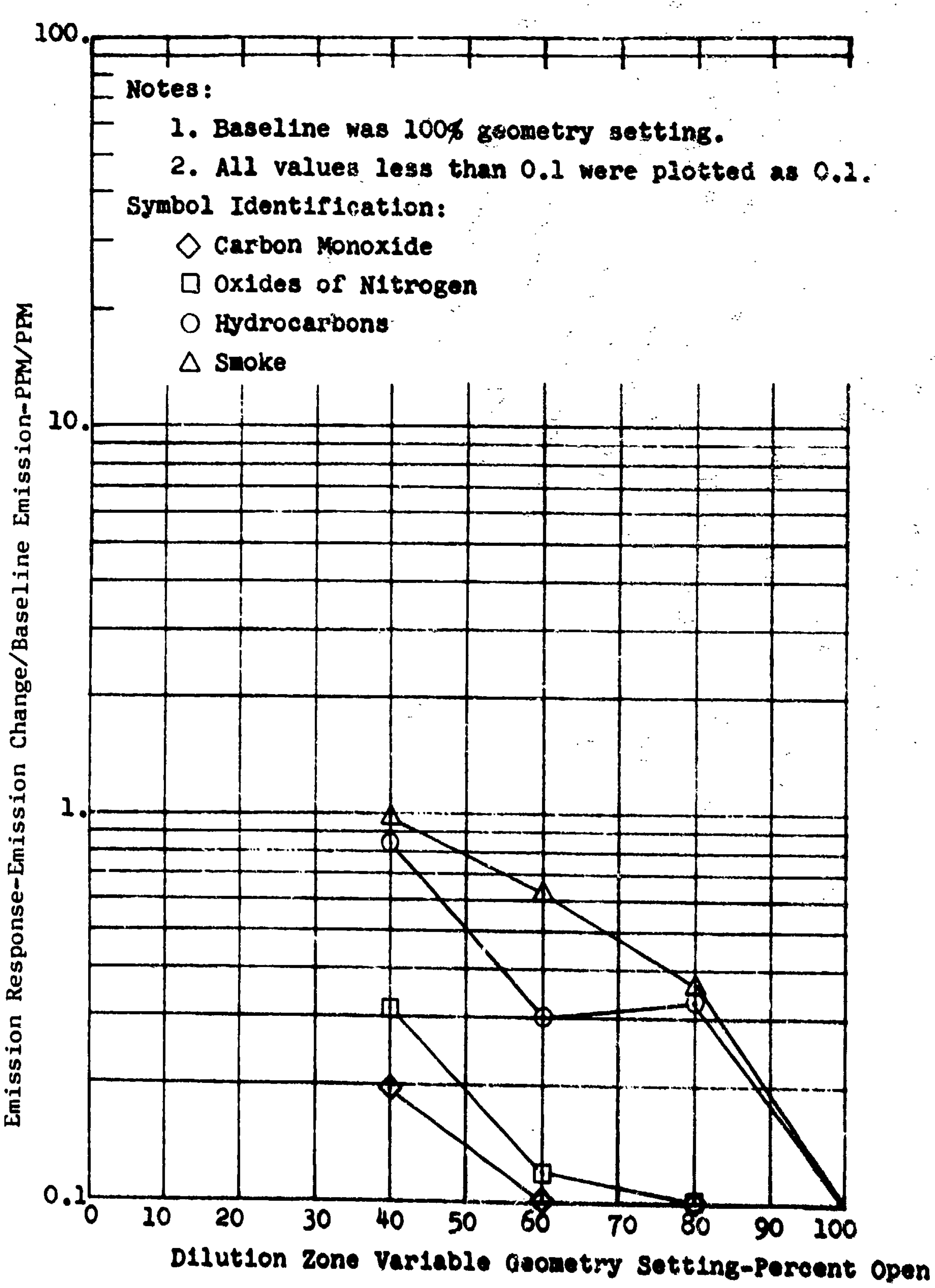


Figure 124. Nonregenerative T63-A-5A Combustor Response of Emission to Variable Geometry, Cycle Point 1 (10% Power).

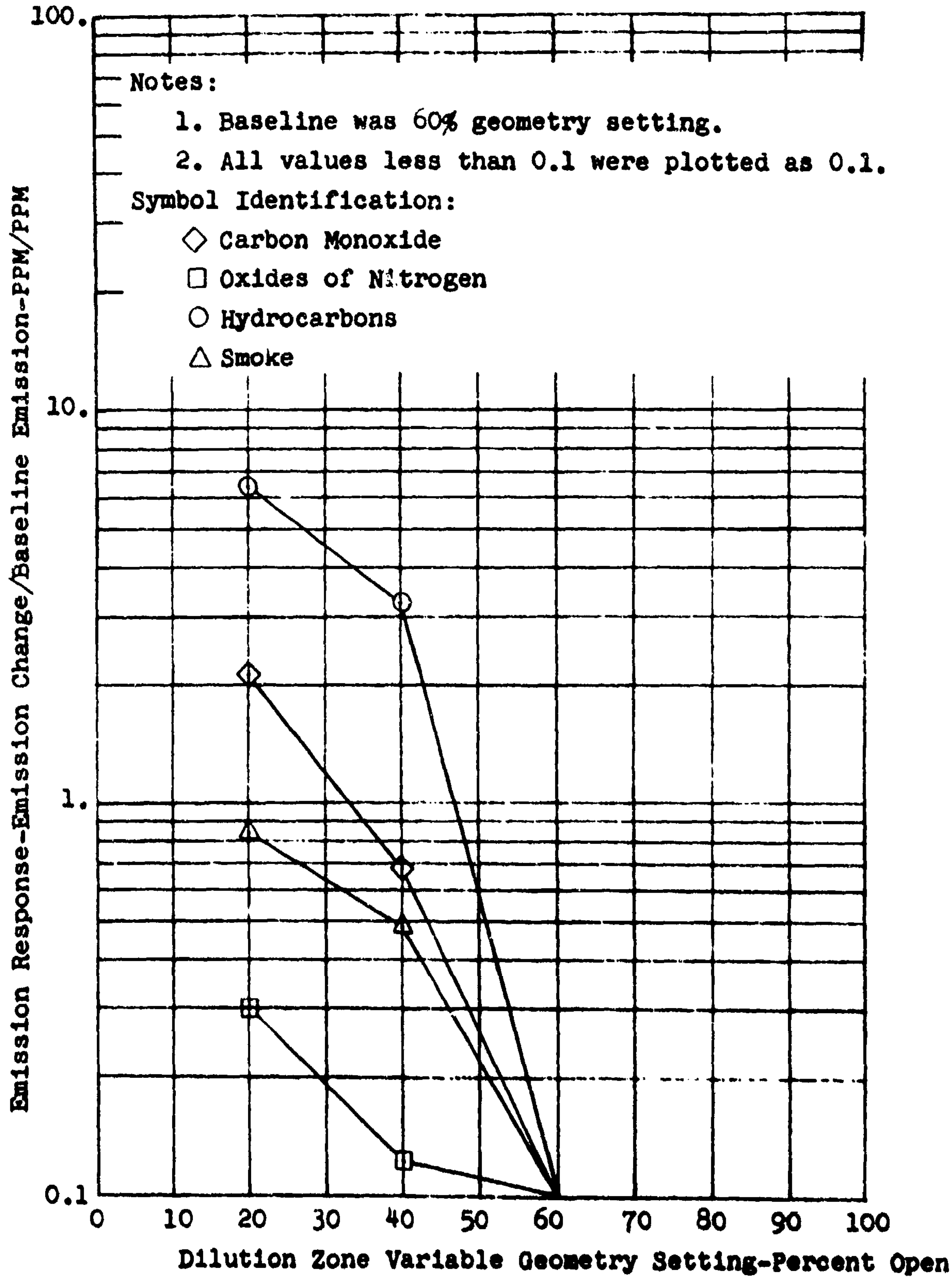


Figure 125. Nonregenerative T63-A-5A Combustor Response of Emission to Variable Geometry Cycle Point 6 (25% Power).

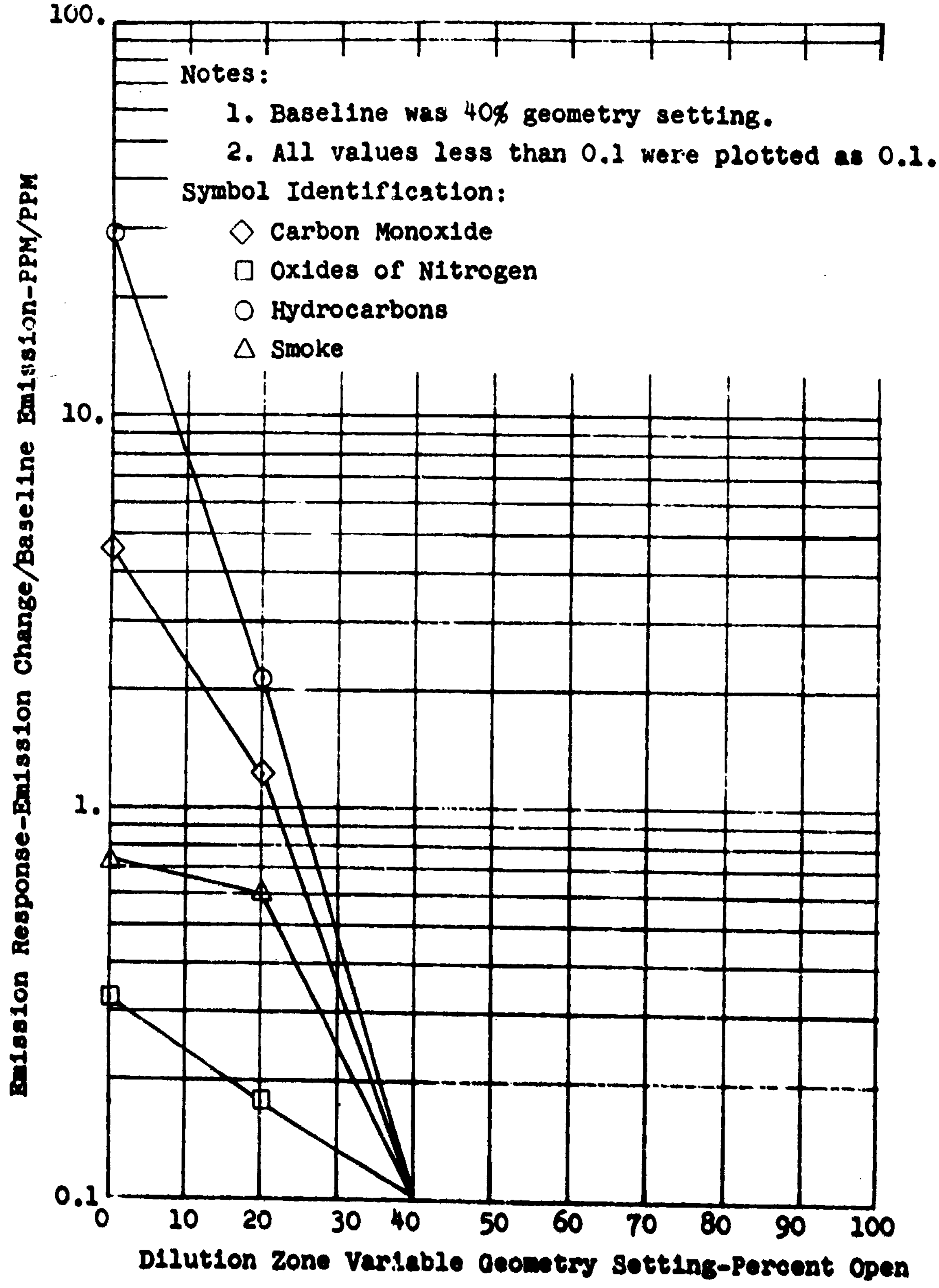


Figure 126. Nonregenerative T63-A-5A Combustor Response of Emission to Variable Geometry Cycle Point 5 (40% Power).

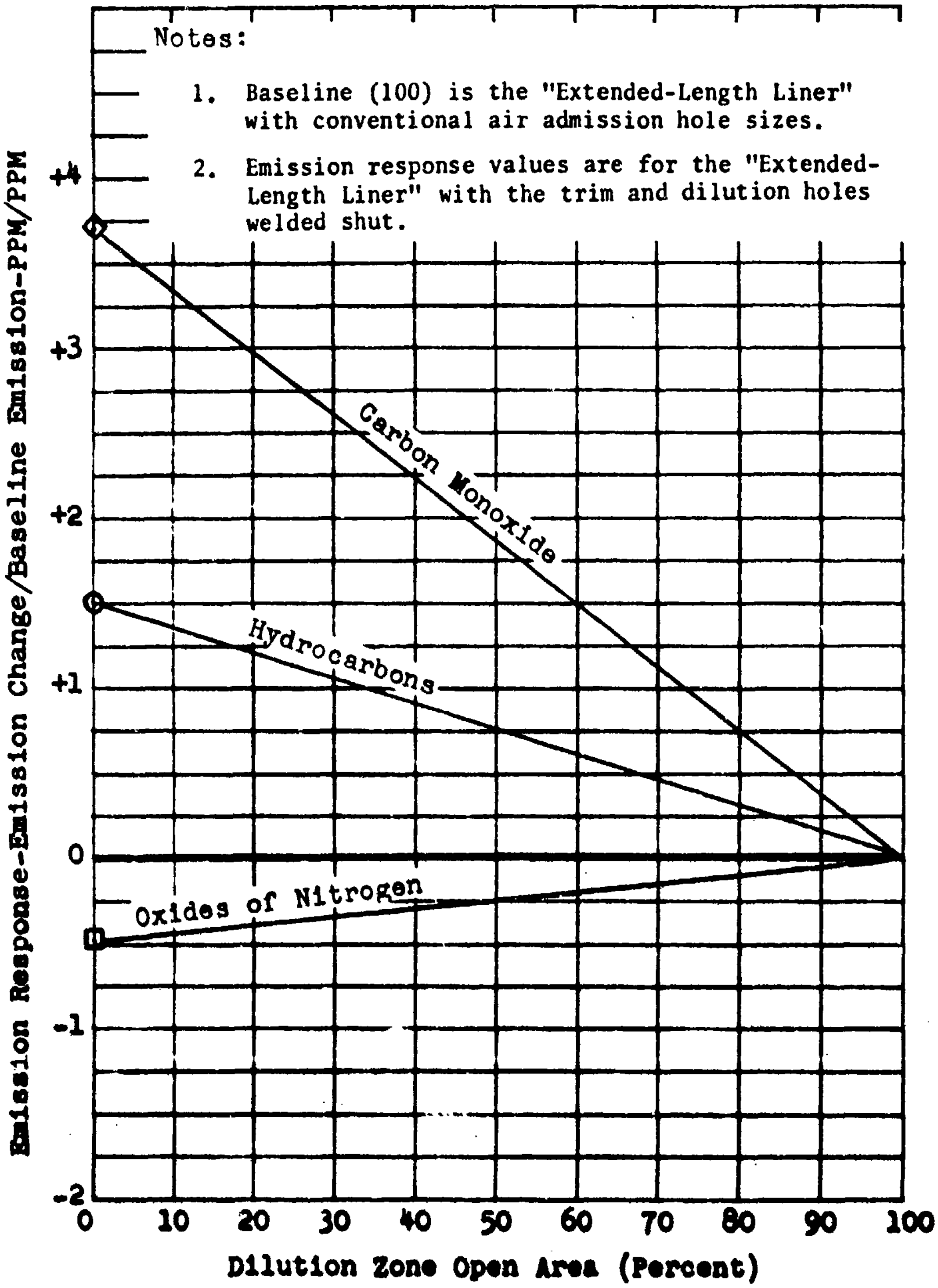


Figure 127. Nonregenerative T63-A-5A Combustor Response of Emission to Airflow Split in Extended-Length Liner at Cycle Point 1 (Max. Power).

- Constrained case:

Percent Power	Dilution-Zone Variable-Geometry Setting
10	40
40	40
55	20
75	0
100	0

- Unconstrained case:

Percent Power	Dilution-Zone Variable-Geometry Setting
10	60
40	40
55	20
75	20
100	0

The emission index values are summarized in Figure 128. The unconstrained case provides 55% reduction in total emissions, and the constrained case gave a 38% reduction as shown in Table XLVI. The contract objective, as stated in the Introduction, is a 50% reduction without an increase in any individual pollutant (constrained case). Therefore, the variable-geometry must be combined with some other low-emission concept to meet the contract objective.

Inspection of the liner and combustor rig hardware after the test showed no apparent damage.

The "Variable-Geometry, Extended-Length Liner" demonstrated an approach for achieving significant total reductions in emissions. The primary payoff in the T63 LOH duty cycle is to control CO and H/C emissions at low power and NO_x and smoke at high power. However, the emission reduction was not enough to meet the contract objective of 50% reduction in total emissions without an increase in any specific pollutant. If the latter restraint is removed, the demonstrated total reduction in emissions was 54.9%. However, with the restraint, the total emission reduction is 37.6%. Therefore,

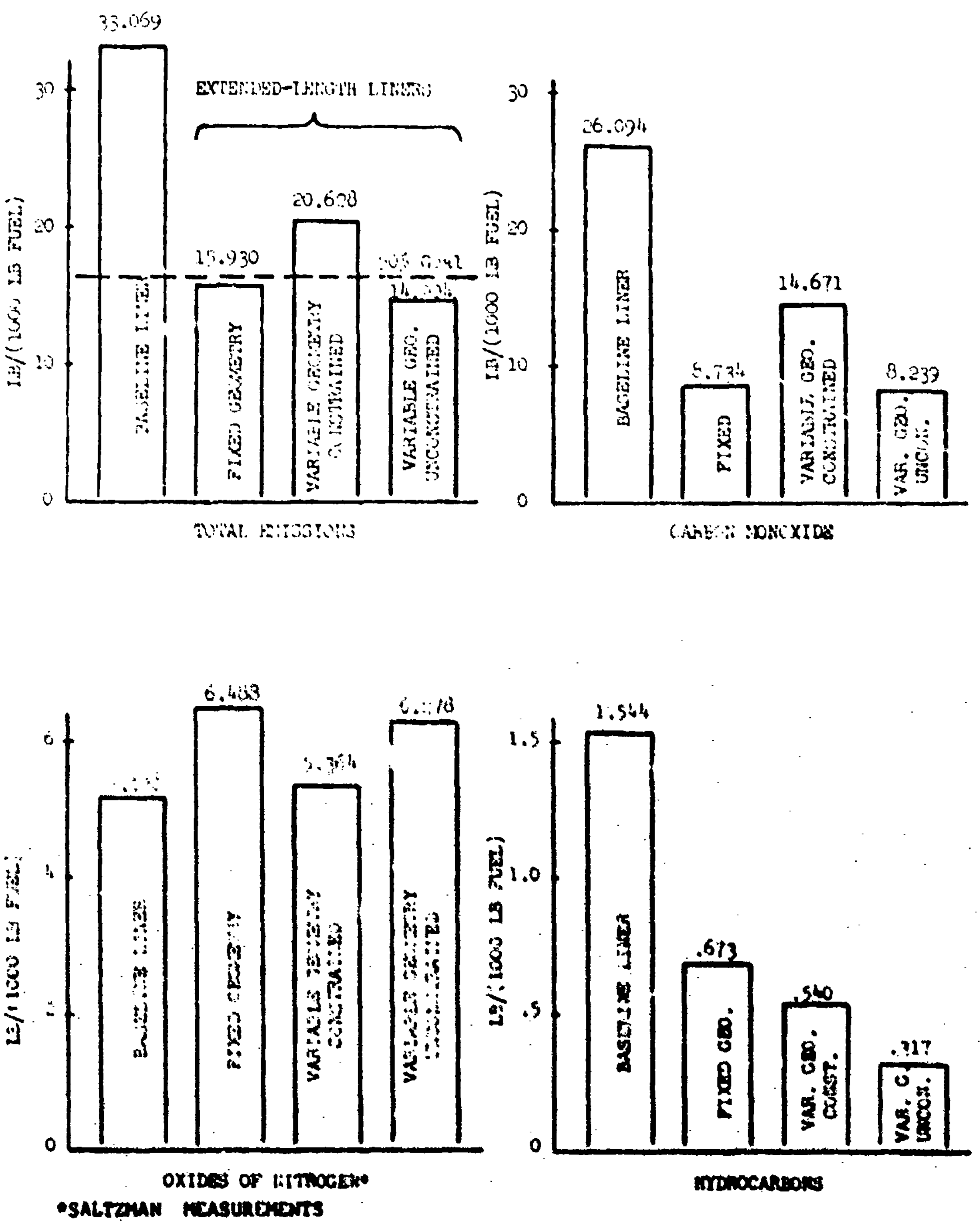


Figure 128. Nonregenerative T63-A-5A Emission Index Comparison with Variable-Geometry Combustor

if variable geometry is applied in the final concept, it must be combined with some other low-emission concept to meet the contract objectives.

EARLY-QUENCH COMBUSTOR

As a result of the Task 2 concept analysis and selection studies, an early-quench concept was selected for experimental evaluation. The concept is to move the primary holes closer to the dome. Task 2 analytical studies indicated that both CO and NO_x should decrease because:

- With the smaller primary zone, the reaction zone residence time is less, thus allowing less time for NO_x formation. The airflow through the primary holes (assuming 50% flow upstream and 50% downstream) which flow downstream quenches the reaction at an earlier time.

- The intermediate temperature zone (distance from primary holes) residence time increases. Thus, additional time is provided to consume the CO, C_xH_y, and carbon.

The early-quench concept was combined with the previously described extended-length concept for experimental evaluation. This combustor liner was termed "Early Quench, Extended-Length Liner".

The modifications made to the conventional T63-A-5A liner to obtain an "Early Quench, Extended-Length Liner" were:

- Add constant-diameter, 6-inch-length section between the primary holes and the film coolant step.

- Close original row of primary holes.

- Add new row of primary holes (same as original, T63 conventional), in new location which is 0.64-inch closer to the dome than the conventional.

The hole patterns and sizes for the "Early-Quench, Extended-Length Liner," "Conventional Liner," and "Extended-Length Liner" are shown in Figure 129. All three liners had the same airflow area split as tabulated below.

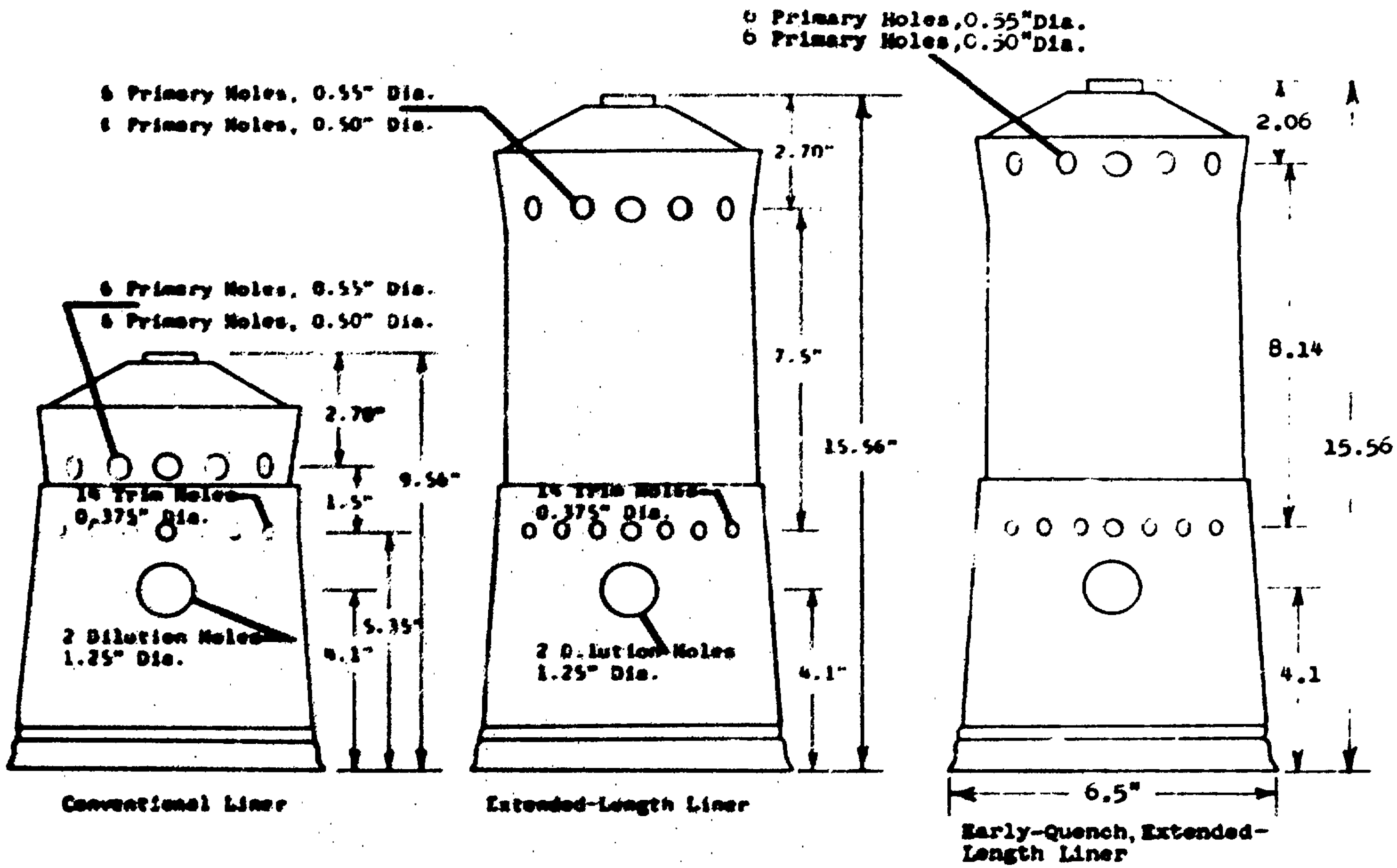


Figure 129. Hole Pattern and Size Comparison of Liners.

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes.	26.3%
Second Cooling Step.	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above calculated flow splits, the primary zone equivalence ratio at T63 maximum power is 0.77.

The "Early-Quench, Extended-Length Liner" which was fabricated for test is shown in Figure 130.

The "Early-Quench, Extended-Length Liner" was tested in a T63 combustor rig at the nonregenerative T63 combustor conditions tabulated in Table IV. The emission, pressure loss, and temperature profile results are summarized and compared with the "Conventional T63-A-5A Liner" and the "Extended-Length Liner" in Table LIV. All three liners were tested with the conventional T63 pressure atomizing fuel injector and JP-4 fuel. As shown in Table LIV, data was not obtained for the "Early-Quench, Extended-Length Liner" at cycle point 1 (idle - 10% power) because of lean blowout. By moving the primary-zone holes closer to the dome, the primary zone was now overloaded and the poor performance at other cycle points could be anticipated.

Oxides of nitrogen, carbon monoxide, hydrocarbon, and smoke emission results for the "Early-Quench, Extended-Length Liner," "Extended-Length Liner," and "Conventional Liner" are plotted in Figures 131 through 134. Comparison of the emission data in these figures shows:

- The predicted reduction (Task 2 studies) in NO_x and CO was not obtained. The probable causes are overloading the primary zone and reduced recirculation.

- For the same size liners ("Early-Quench, Extended-Length Liner" and "Extended-Length Liner"), the early quench effect was to increase the CO, C_xH_y, and smoke. The NO_x was approximately the same for both extended-length liners. If the Saltzman, NO_x analysis is assumed to be valid, the NO_x increased slightly. If the NDIR + NDUV, NO_x analysis is assumed to be valid, the NO_x decreased slightly with early quench.

Figure 130. Preliminary Low-Emission, Early-Quench, Extended-Length Liner.

TABLE LIV. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, (3) EARLY-QUENCH, LONG LINER.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	60.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Early Quench-Long Liner	Blow-Out					
A. Emissions						
CO, (ppm)		465.2	389.9	257.6	139.	56.7
H/C, (ppm)		120.0	38.0	10.4	2.1	1.2
NO_x, (On-Line, NDIR & NDUV) (ppm)		27.5	35.0	42.0	68.0	111.5
NO_x, (Saltzman) (ppm)		29.0	42.8	57.1	82.6	124.1
Smoke Number			11.5	12.9	20.5	22.5
B. Pressure Loss (%)		4.59	4.91	4.78	4.68	4.36
C. Temp. Profile (T_{max}/T_{avg})		1.3023	1.206	1.2519	1.1938	1.1611

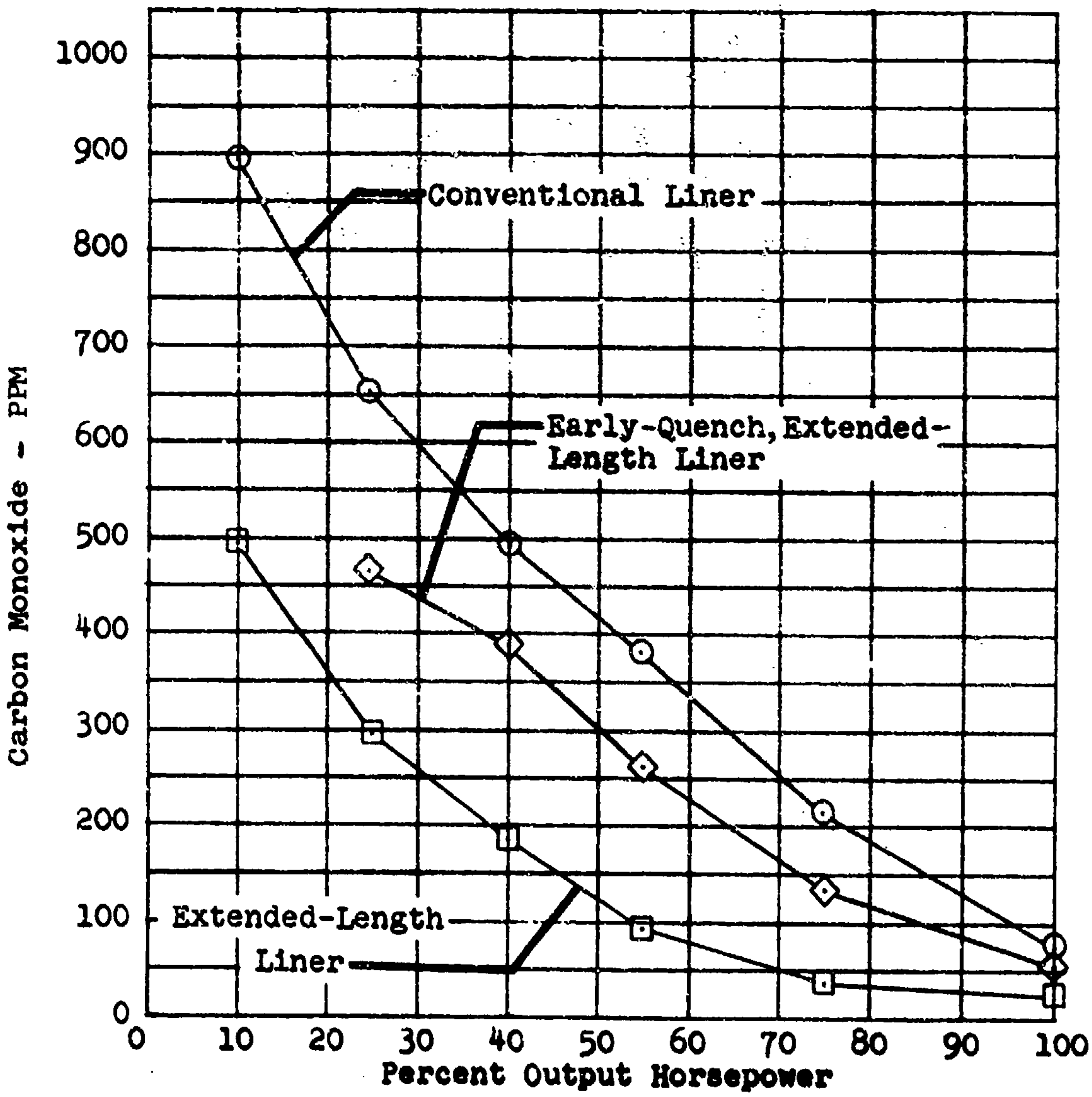


Figure 131. Nonregenerative T63-A-5A Combustor Carbon Monoxide Data Comparison for Conventional Liner.

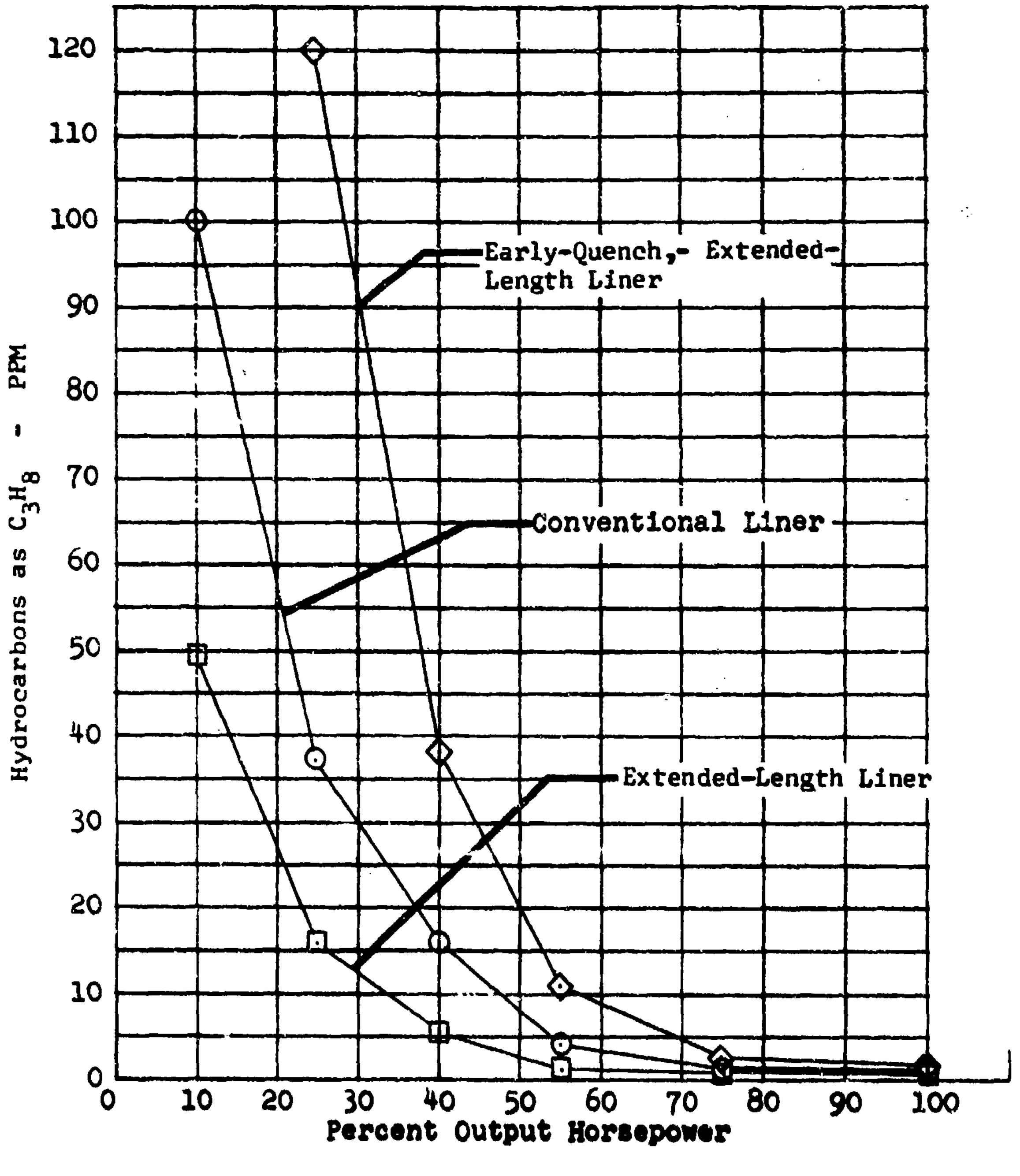


Figure 132. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Conventional Liner, Extended-Length Liner, Early-Quench Liner.

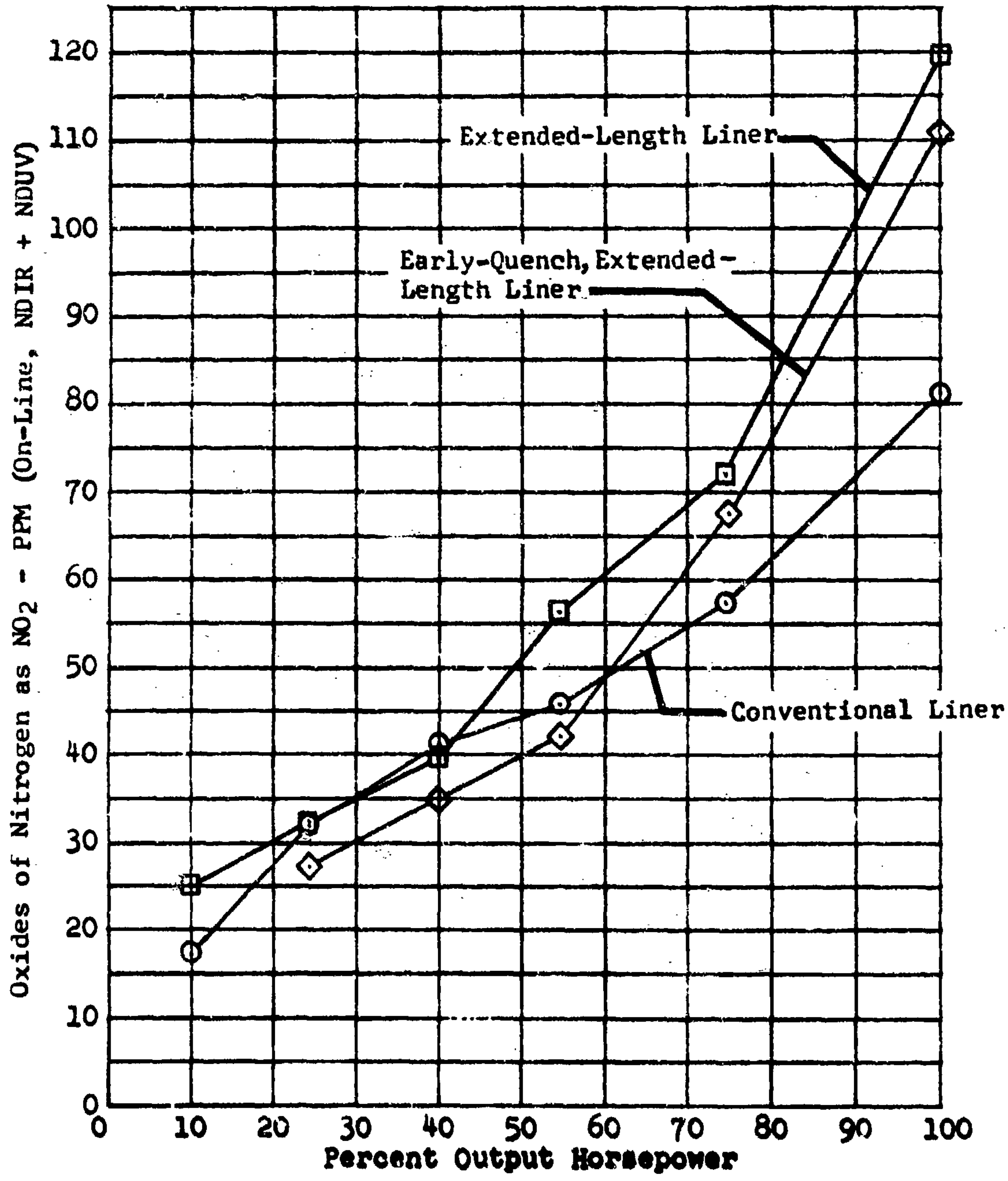


Figure 133. Nonregenerative T63-A-5A Combustor Oxides of Nitrogen Data Comparison for Conventional Liner.

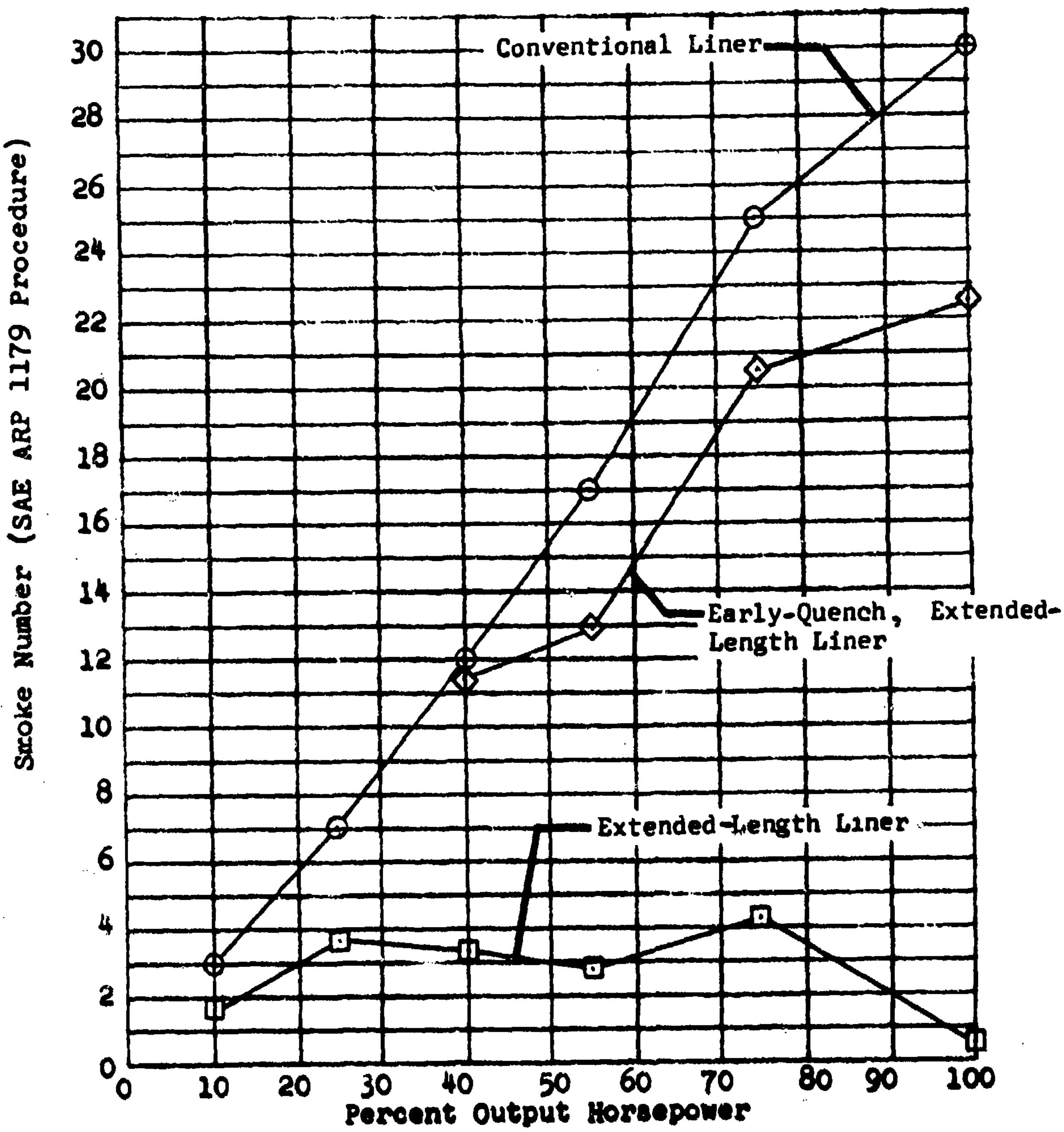


Figure 134. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Conventional Liner, Extended-Length Liner, Early-Quench Liner.

The emission data shown in Figures 131 through 134 as PPM were converted to emission index for the LOH duty cycle. The relative emission index values for the three liners, as presented in Figure 135, show that for the same size liners (extended-length), the early quench significantly increased the total emissions. Early quench also degraded the temperature profile as shown in Table LIV.

The early-quench approach used in this particular study significantly increased the emissions. This was probably due to overloading of the primary (reaction) zone and reduced primary-zone recirculation. Perhaps there is a better approach for achieving early quench in the T63 combustor, such as moving some of the dilution zone air forward instead of moving the primary-zone forward. This would probably reduce the NO_x but the CO, C_xH_y, and smoke would increase. A better "total-emission" approach would be to move the first-row primary holes further from the dome to increase the primary-zone volume. This would probably cause a small increase in NO_x but might significantly reduce the CO, C_xH_y and smoke.

The early-quench approach tested for the T63 combustor did not improve the emission reduction and its inclusion in the final concept was not recommended.

The effect on emissions of moving the primary-zone holes to the rear instead of forward should be experimentally investigated in an extended-length liner.

DELAYED DILUTION COMBUSTOR

The "Extended-Length" combustor concept, as previously discussed in this appendix, reduced the total emissions by 52%. However, the "Extended-Length" combustor was 6 inches longer than the conventional T63-A-5A combustor. The same concept of delayed-dilution, combustor could be applied in the conventional-length T63-A-5A combustor by a redesign to relocate the trim and dilution holes. The delayed dilution would increase the residence time in the intermediate zone. As shown in the Task 2 analytical studies and the experiments with the "Extended-Length" combustor, the CO, C_xH_y and C emissions should decrease and the NO_x should increase slightly.

The delayed-dilution concept was applied to the conventional-length T63-A-5A combustor to determine the effect on emission performance. The only modifications made to the conventional T63-A-5A liner to obtain a "Standard-Length, Delayed-Dilution Liner" were:

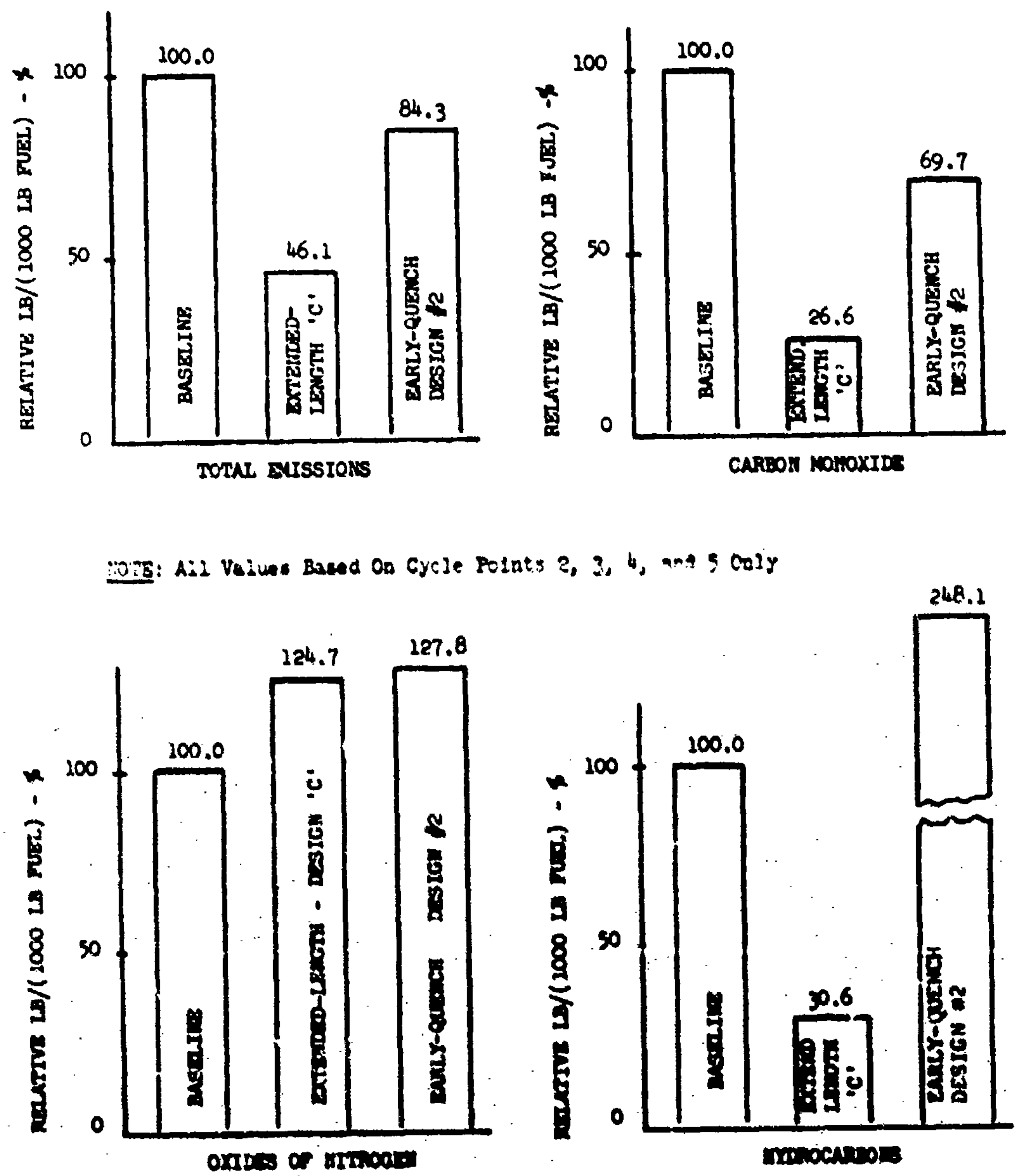


Figure 135. Nonregenerative T63-A-5A Emission Index Comparison with Early-Quench Combustor.

- Close the trim and dilution holes in the conventional liner.
- Add six 0.921 inch-diameter dilution holes, equally spaced, at a distance of 2.1 inches from the liner exit. (The hole area of these six dilution holes is equal to the total area of the trim and dilution holes in the conventional liner.)

The hole pattern and size comparison for the "Standard-Length, Delayed-Dilution-Zone Liner" with the "Conventional Liner" is shown in Figure 136. The primary design change, as it influences emissions, was to increase the reaction length for consuming the CO, C_xH_y, and carbon from 1.5 inches to 4.76 inches prior to the final quench. The airflow area split was the same for both liners, as shown in Figure 136, and is tabulated below:

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes.	26.3%
Second Cooling Step.	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above calculated splits, the primary-zone equivalence ratio at maximum power is 0.77.

The "Standard-Length, Delayed-Dilution-Zone Liner" which was fabricated for test is shown in Figure 137.

The "Standard-Length, Delayed-Dilution-Zone Liner" was tested in a T63 combustor rig at the nonregenerative T63 combustor conditions tabulated in Table IV. The emission, pressure loss, and temperature profile results are summarized and compared with the "Conventional T63-A-5A Liner" and the "Extended-Length Liner" in Table LV.

Oxides of nitrogen, carbon monoxide, hydrocarbon, and smoke emission results for the "Standard-Length, Delayed-Dilution-Zone Liner" are compared with the emissions from the "Conventional Liner" and "Extended-Length Liner" in Figures 138 through 141. Compared to the "Conventional Liner", as predicted in the Task 2 concept studies, significant reductions were obtained in CO, C_xH_y, and smoke. The NO_x was approximately the same. However, the reduction in CO, H/C, and smoke was not as great as the "Extended-Length Liner." This is as predicted because the "Extended-Length Liner" had a longer residence time in the intermediate zone in which to consume the CO, C_xH_y, and carbon.

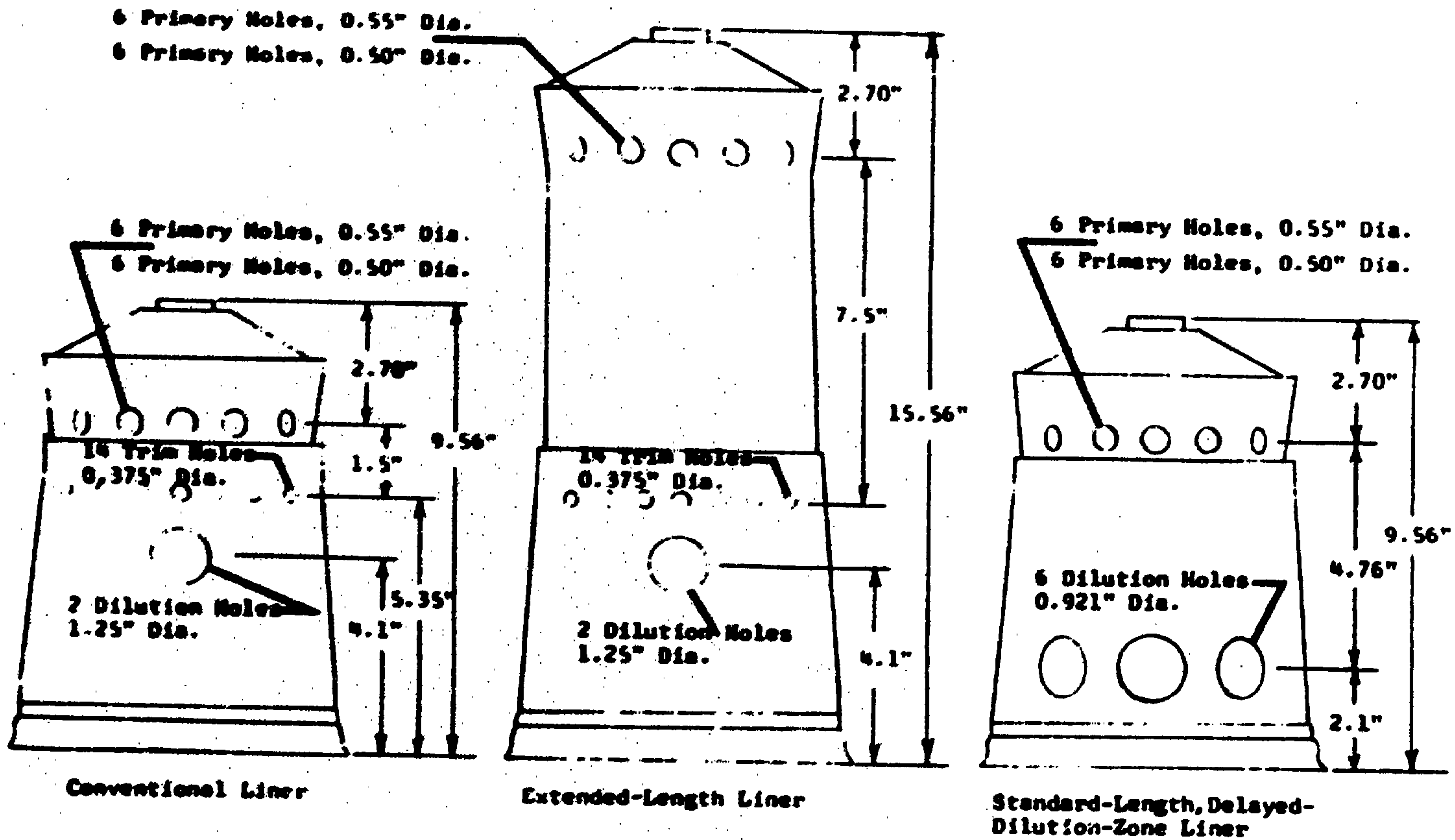


Figure 136. Hole Pattern and Size Comparison of Liners.

Figure 137. Preliminary Low-Emission, Standard-Length, Delayed-Dilution-Zone Liner.

TABLE LV. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, (3) STANDARD-LENGTH, DELAYED-DILUTION-ZONE LINER

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Standard Length-Delayed Dilution Zone						
A. Emissions						
CO, (ppm)	619	412	273	183.4	100.0	41.2
H/C, (ppm)	70.	18.4	6.0	2.6	1.1	0.8
NO_x, (On-Line, NDIR & NDUV) (ppm)	21.	24.	30.5	44.5	58.5	97.5
NO_x, (Saltzman*) (ppm)	23.1	35.3	45.2	65.4	77.8	115.5
Smoke Number	2.50	4.85	4.20	7.42	13.0	15.5
B. Pressure Loss (%)	5.42	5.55	5.57	5.18	5.02	4.34
C. Temp. Profile (T_{max}/T_{Avg})	1.222	1.201	1.187	1.157	1.155	1.151

*The Saltzman data for this liner might not be correct due to spectrophotometer electronic problems.

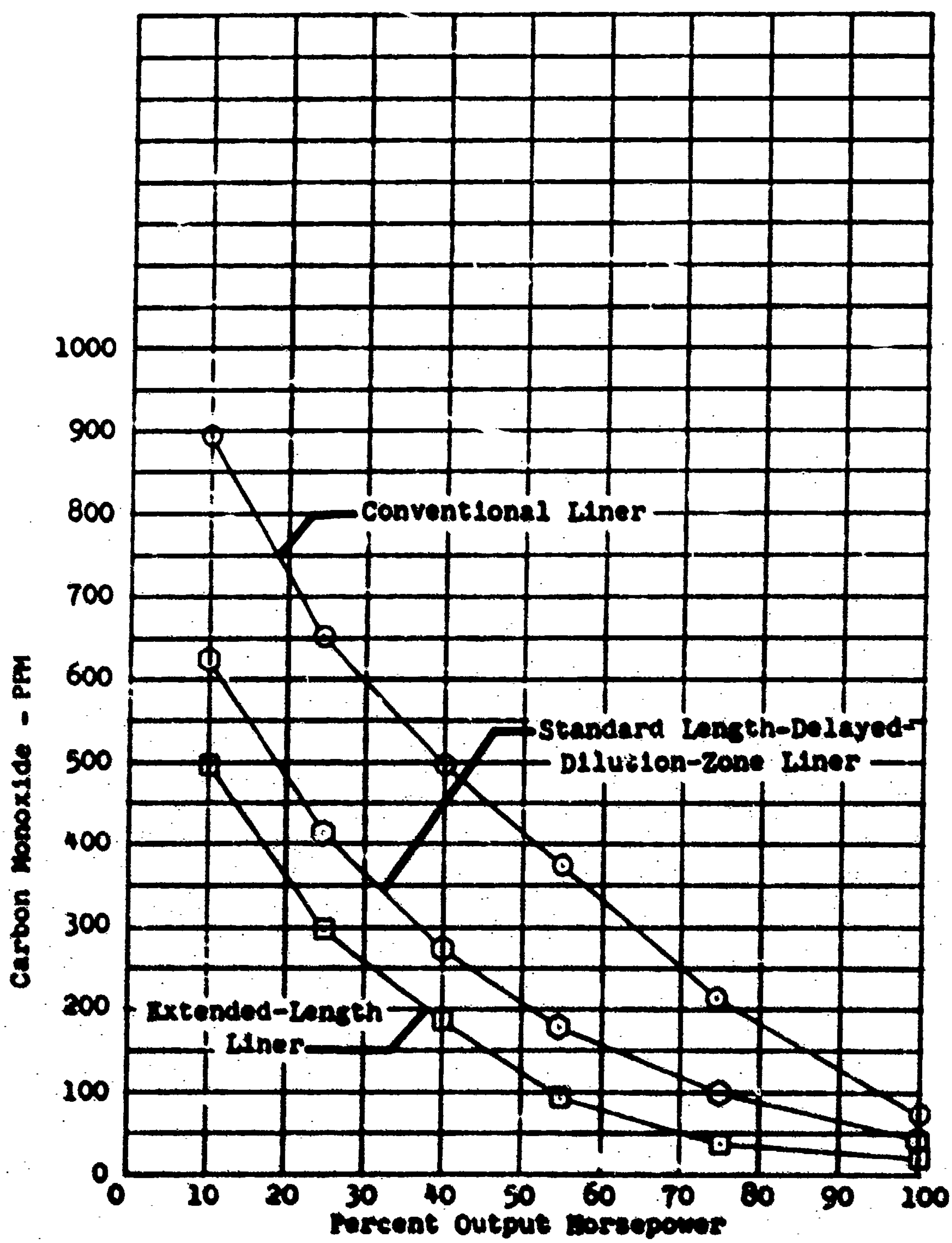


Figure 138. Nonregenerative T63-A-5A Combustor Carbon Monoxide Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor and T63 Baseline Combustors.

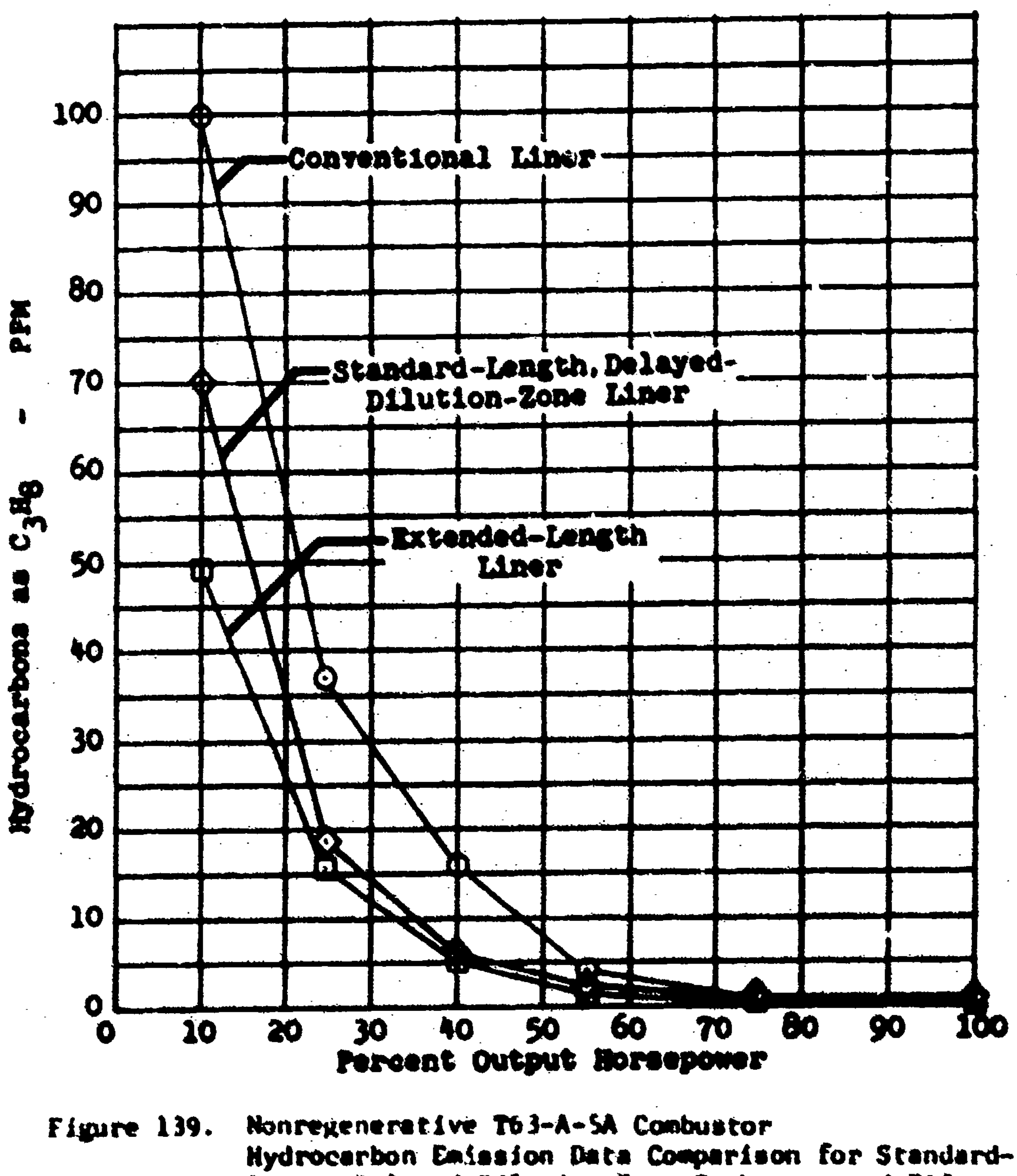


Figure 139. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

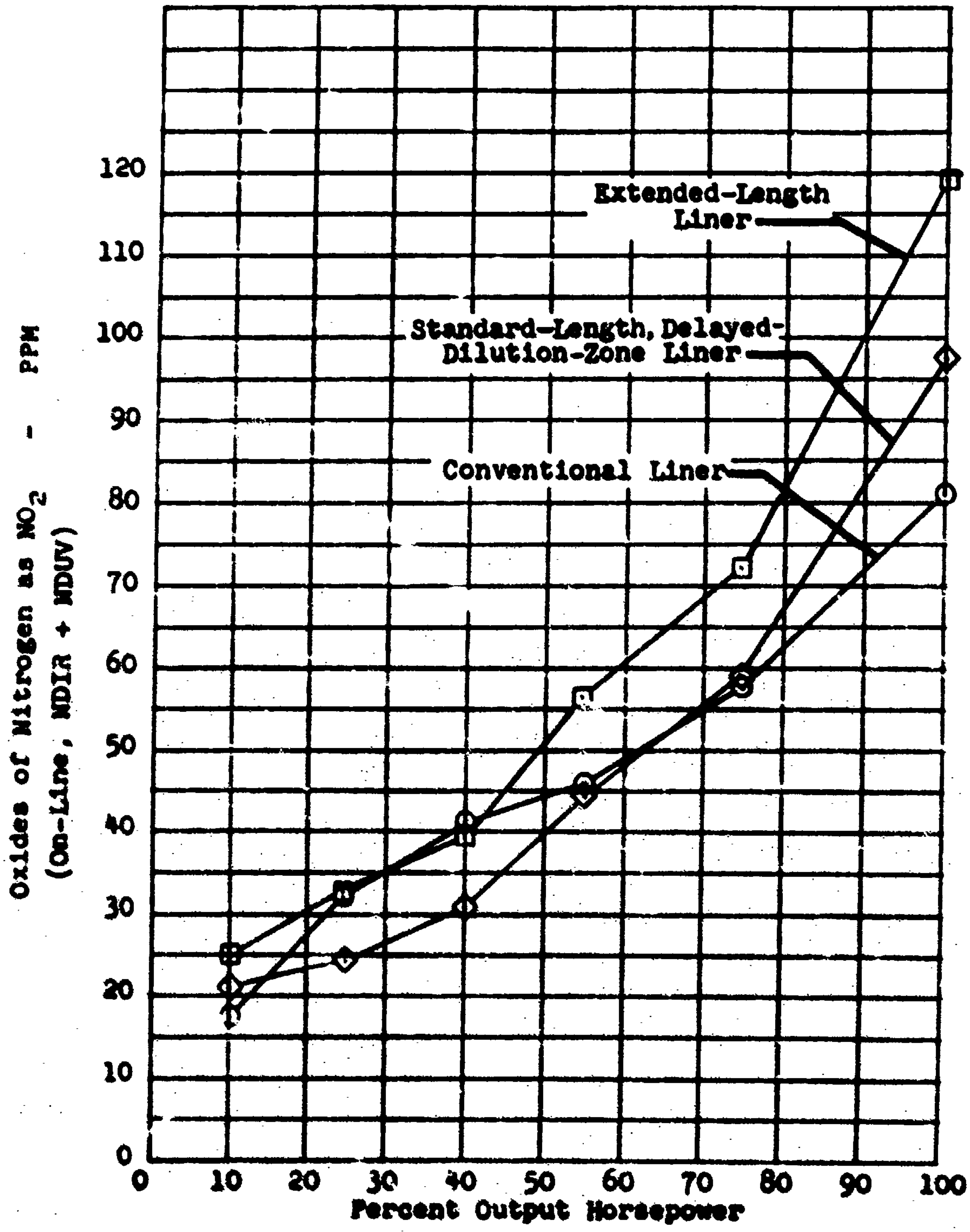


Figure 140. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

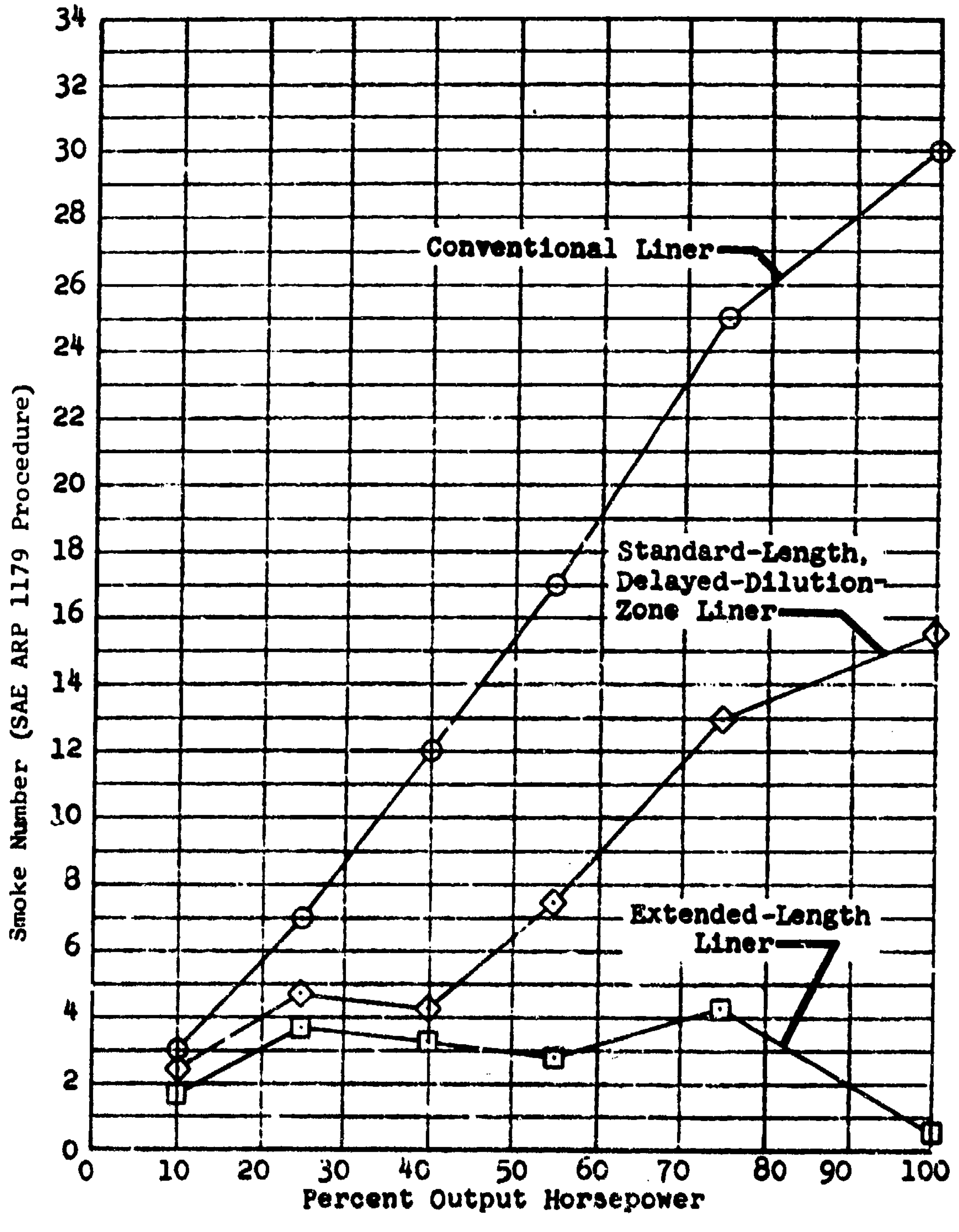


Figure 141. Nonregenerative [illegible]63-A-5A Combustor Smoke Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

The emission data shown in Figures 138 through 141 as PPM were converted to emission index for the LOH duty cycle. As shown in Figure 142 and Table XLVI, the total emissions were reduced 38% without any increase in individual emissions. Although this simple liner modification did not meet the contract objectives of 50% reduction, it does demonstrate that this feature of delayed dilution should be incorporated into the final concept selection.

One problem of major concern in the "Standard-Length, Delayed Dilution Liner" concept was the effect on temperature profile. This potential problem exists because of shorter distance for the dilution air to mix with primary-zone air. The temperature profile results, presented in Figure 143, show that it was worse than the "Conventional Liner" but about the same as the "Extended-Length Liner." Although the profile is probably not acceptable for an engine, it is a less severe problem than anticipated and could be resolved in a development program. No attempt was made in the design to optimize the dilution hole size or radial locations. However, in the next concept, a preliminary evaluation will be made of one approach for improving the temperature profile. The approach will incorporate a smaller L/D dilution zone.

Inspection of the liner and combustor rig hardware after the test showed no apparent damage.

The "Standard-Length, Delayed-Dilution-Zone Liner" demonstrated a simple approach for achieving significant reductions (38%) in the emissions from the T63-A-5A combustor. This concept, if combined with other concepts, could probably meet the contract objective of 50% reduction in emissions.

DELAYED/ANNULAR DILUTION COMBUSTOR

This combustor concept was the same approach as the previous delayed dilution concept except that an extension to the standard turbine bearing support centerbody was included to create a single-sided annular dilution design. It was anticipated that a single-sided annular dilution might improve the dilution air mixing by allowing a higher L/D region between the dilution holes and combustor exit.

The centerbody extension was an air-cooled, all-metal centerbody extension. The modifications made to the conventional T63-A-5A liner to obtain a "Standard-Length, Delayed-Dilution, Annular-Dilution Liner" were:

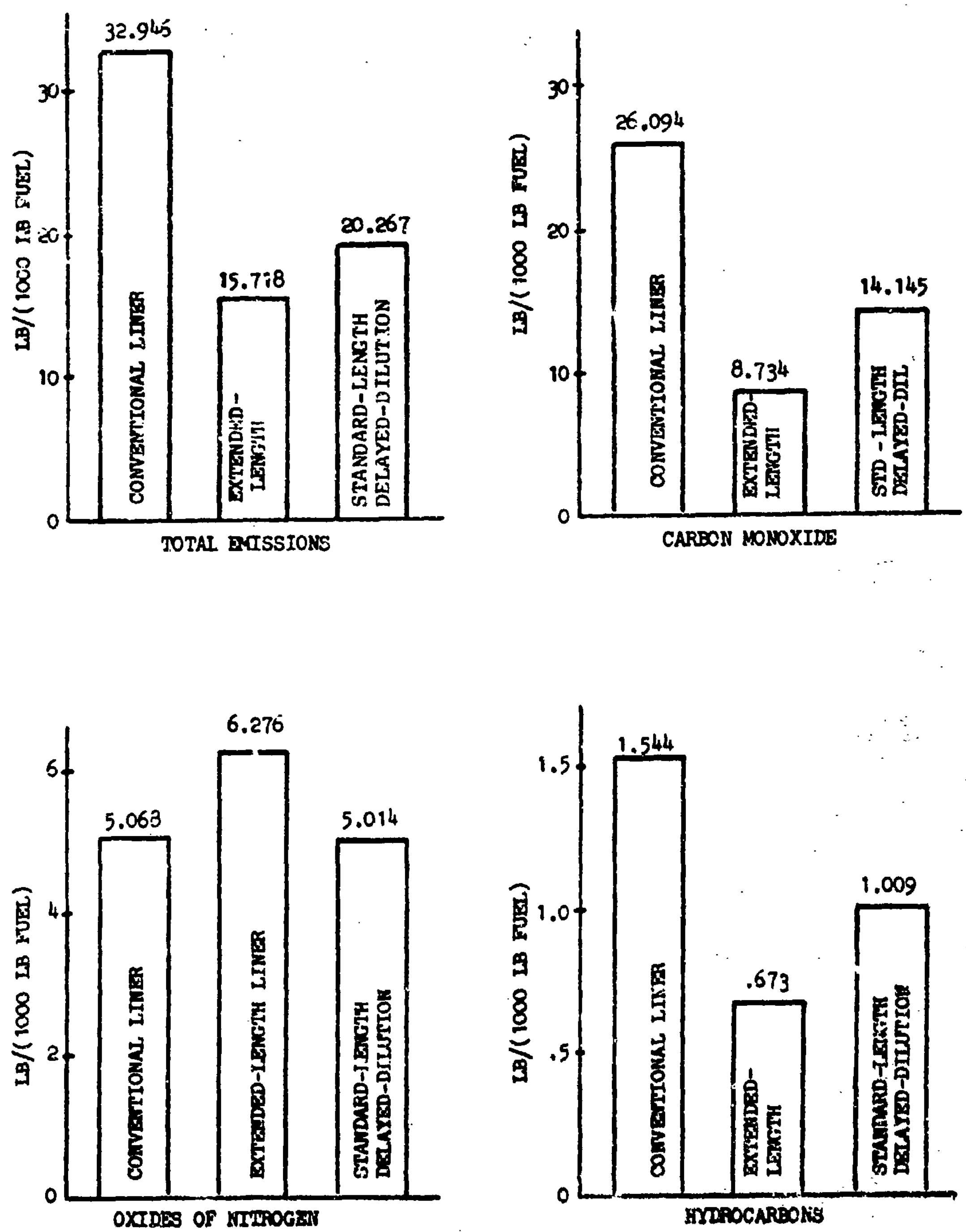


Figure 142. Nonregenerative T63-A-5A Emission Index Comparison with Delayed-Dilution Combustor.

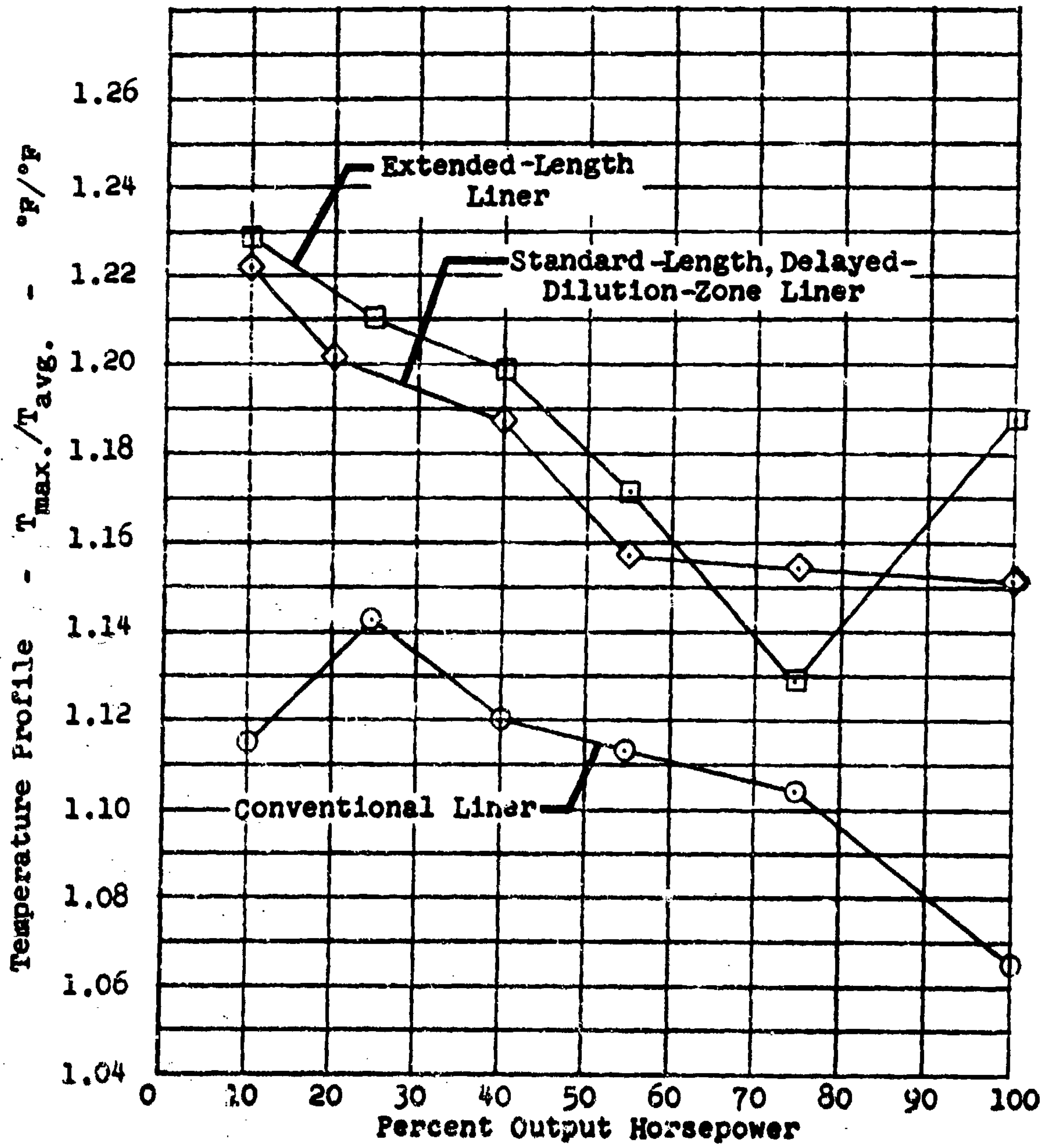


Figure 143. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

- Close the trim and dilution holes in the conventional liner.
- Add twenty 0.285-inch x 0.714-inch dilution holes, equally spaced, at a center distance of 2.1 inches from the liner exit. (The hole areas of these twenty dilution holes are equal to the total area of the trim and dilution holes in the conventional liner.
- Add an air-cooled all-metal centerbody extending 3.12 inches upstream from the liner exit. Size the cooling holes for 3.9% of the combustor airflow.

The hole pattern and size comparison for the "Standard-Length Delayed-Dilution,Annular-Dilution Liner" with the "Conventional Liner" is shown in Figure 144. The primary design change, as it influences emissions, was to increase the intemediate-zone reaction length for consuming the CO, C_xH_y, and carbon. The length was increased from 1.5 inches to 4.76 inches. The airflow area split was slightly different. The flow splits and primary-zone equivalence ratios are tabulated below:

Location	Conventional and Extended-Length Liners	Standard-Length, Delayed-Dilution, Annular-Dilution Liner
Dome Holes	11.8%	11.3%
First Cooling Step	11.2%	10.7%
Primary Holes	26.3%	25.4%
Second Cooling Step	11.2%	10.7%
Trim Holes	15.2%	-
Dilution Holes	24.3%	38.0%
Dilution Centerbody Cooling	-	3.9%
	100.0%	100.0%
Primary Zone Equivalence Ratio	0.77	0.80

With the above calculated flow splits, the primary-zone equivalence ratio at maximum power is 0.77 for the conventional liner and 0.80 for the delayed/annular dilution liner.

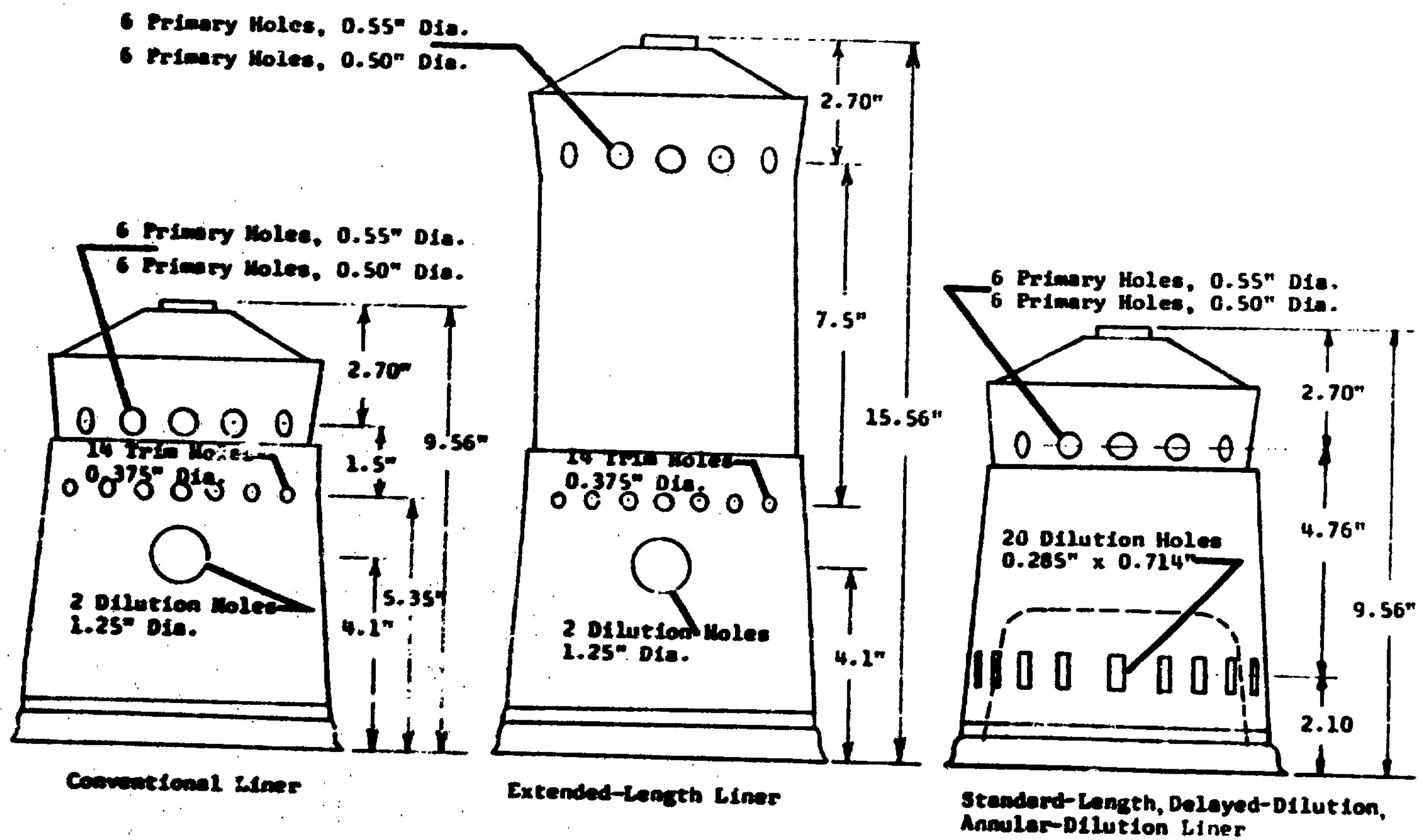


Figure 144. Hole Pattern and Size Comparison of Liners.

The "Standard-Length, Delayed-Dilution, Annular-Dilution Liner" which was fabricated for test is shown in Figures 145 and 146.

The "Standard-Length, Delayed-Dilution, Annular-Dilution Liner" was tested in a T63 combustor rig at the nonregenerative T63 combustor conditions tabulated in Table IV. The emission, pressure loss, and temperature profile results are summarized and compared with the "Conventional T63-A-5A" and the "Standard-Length, Delayed-Dilution" combustors in Table LVI.

Carbon monoxide, hydrocarbon, oxides of nitrogen, and smoke emission results for the "Standard-Length, Delayed-Dilution, Annular-Dilution Liner" are compared with the emissions from the "Conventional Liner," "Extended-Length Liner" and "Standard-Length, Delayed-Dilution" in Figures 147 through 150. Compared to the "Conventional Liner" as predicted in the Task 2 concept studies, significant reductions were obtained in CO and C_xH_y. The NO_x was approximately the same, but the smoke was higher for all conditions. The reduction in CO and H/C was not as great as for the "Extended-Length Liner." This is as predicted because the "Extended-Length Liner" had a greater reaction-zone length in which to consume the CO C_xH_y, and carbon.

The emission data shown in Figures 147 through 150 as PPM were converted to emission index for the LOH duty cycle. As shown in Figure 151, which compares both standard-length delayed-dilution combustion liners, the total emissions were reduced 34% for the delayed/annular-dilution liner without any increase in individual emissions. Although this simple liner modification did not meet the contract objectives of 50% reduction, it does demonstrate that this feature of delayed dilution should be incorporated into the final concept selection.

One problem of major concern in the "Standard-Length, Delayed-Dilution, Annular-Dilution Liner" concept was the deterioration of the exit temperature profile. This problem exists because of shorter distance for the dilution air to mix with primary-zone air and because the annular dilution does not permit circumferential mixing. The temperature profile results are presented in Figure 152 and show that the "Standard-Length, Delayed-Dilution, Annular-Dilution Liner" was much worse than the "Conventional Liner", "Extended-Length Liner," and "Standard-Length, Delayed-Dilution Liner." No attempt was made in the design to optimize the dilution hole size or radial locations.

Inspection of the liner and combustion rig hardware after the test showed no apparent damage.

The "Standard-Length, Delayed-Dilution-Zone Liner" demonstrated a simple approach for achieving significant reductions (34%) in

Figure 145. Preliminary Low-Emission, Standard-Length, Delayed-Annular Dilution, T63 Combustor Liner - External View.

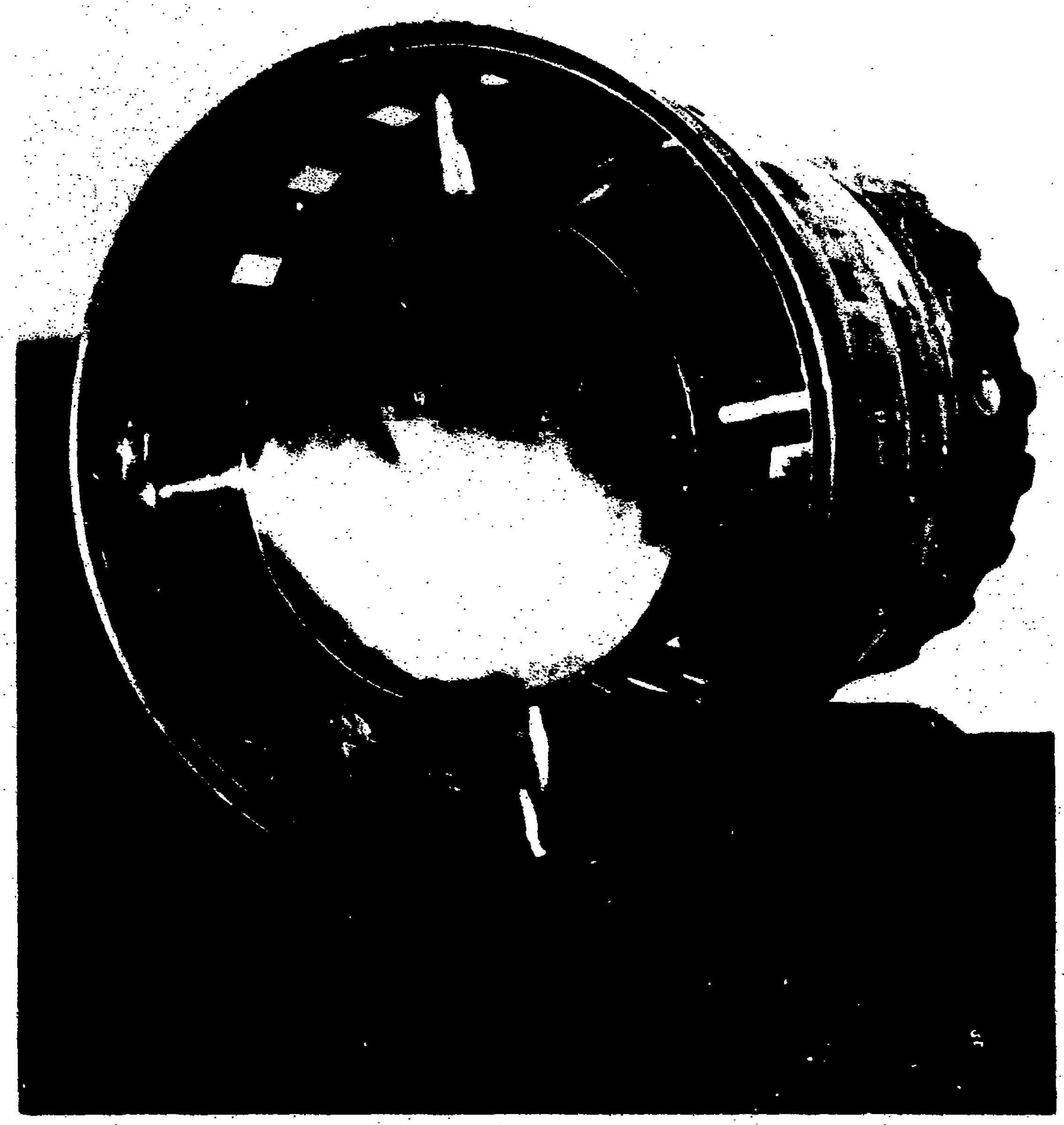


Figure 146. Preliminary Low-Emissions, Standard-Length, Delayed-Dilution, Annular-Dilution T63 Combustor Liner - Internal View.

TABLE LVI. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER; (2) STANDARD-LENGTH, DELAYED-DILUTION, ANNULAR-DILUTION-ZONE LINER; (3) STANDARD-LENGTH, DELAYED-DILUTION-ZONE LINER

	Cycle Point					
I. Conventional Liner						
A. Emissions	1	6	5	4	3	2
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Standard-Length, Delayed-Dilution, Annular-Dilution Zone Liner						
A. Emissions						
CO, (ppm)	525.3	376.0	300.9	223.4	142.9	72.5
H/C, (ppm)	65.0	26.0	12.8	5.0	1.2	.8
NO_x, (On-Line, NDIR & NDUV) (ppm)	24.5	25.0	31.5	39.5	52.0	86.5
NO_x, (Saltzman) (ppm)	19.6	30.9	38.1	45.2	60.1	89.6
Smoke Number	4.40	11.6	15.50	20.55	30.43	-
B. Pressure Loss (%)	5.78	5.35	5.93	5.84	5.24	4.99
C. Temp. Profile (T_{max}/T_{avg})	1.335	1.325	1.272	1.250	1.248	1.192
III. Standard-Length, Delayed-Dilution Zone						
A. Emissions						
CO, (ppm)	619	412	273	183.4	100.0	41.2
H/C, (ppm)	70.	18.4	6.0	2.6	1.1	0.8
NO_x, (On-Line, NDIR & NDUV) (ppm)	21.	24.	30.5	44.5	58.5	97.5
NO_x, (Saltzman*) (ppm)	25.1	35.3	45.2	65.4	77.8	115.5
Smoke Number	2.50	4.05	4.20	7.42	13.0	15.5
B. Pressure Loss (%)	5.42	5.55	5.57	5.18	5.02	4.34
C. Temp. Profile (T_{max}/T_{Avg})	1.222	1.241	1.187	1.157	1.155	1.151

*The Saltzman data for this liner might not be correct due to spectrophotometer electronic problems.

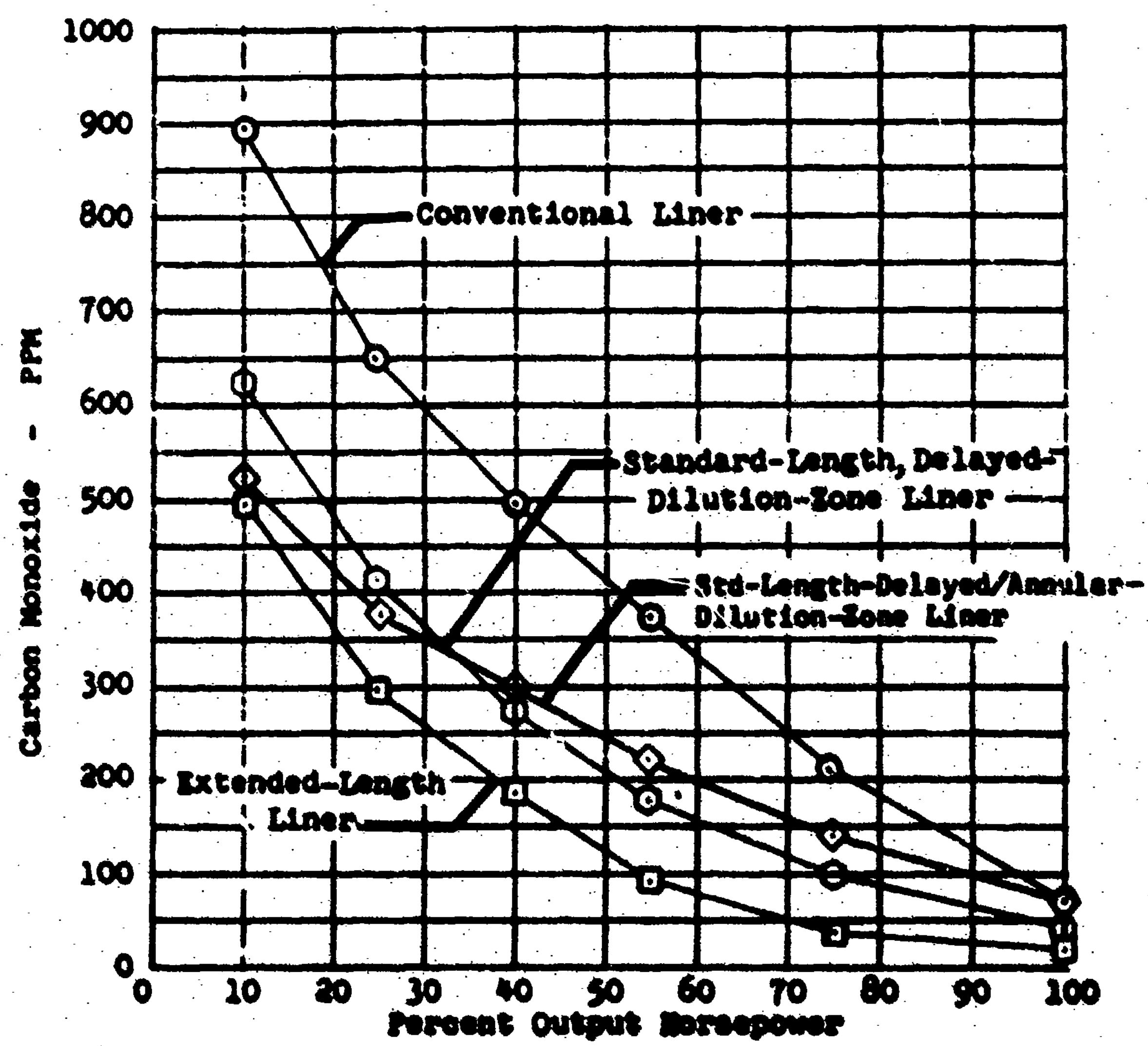


Figure 147. Nonregenerative T63-A-5A Combustor Carbon Monoxide Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor and T63 Baseline Combustors.

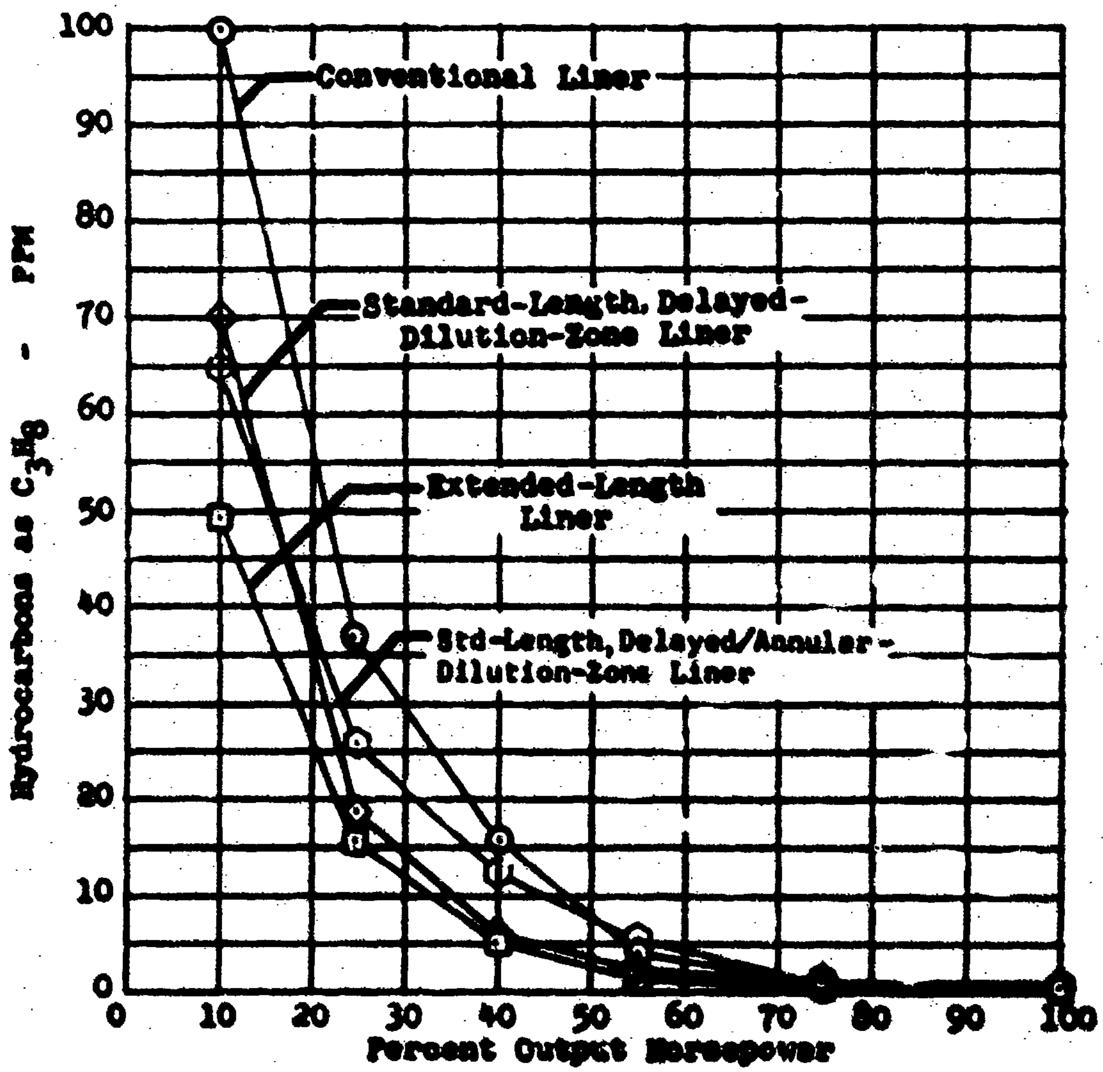


Figure 148. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

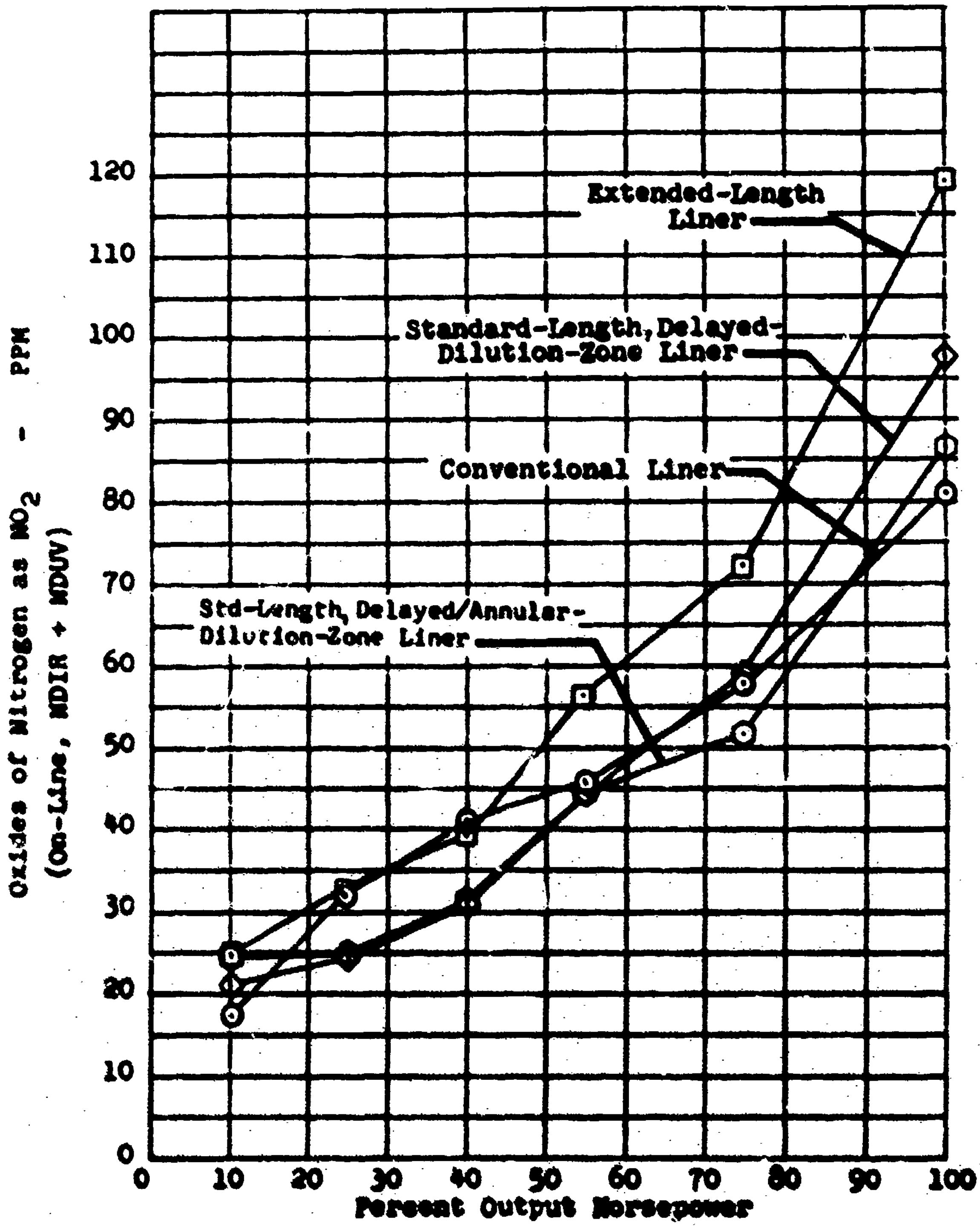


Figure 149. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

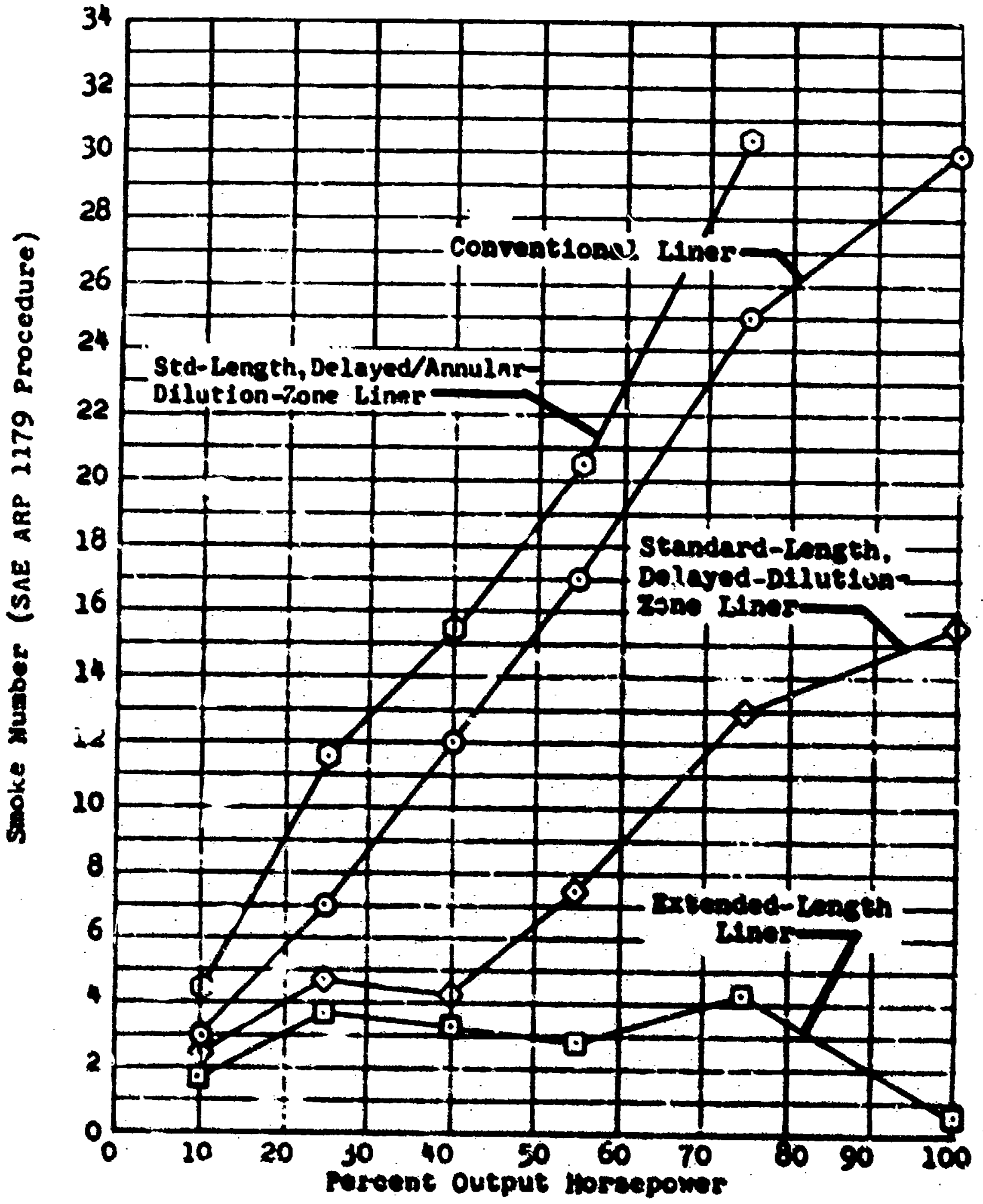


Figure 150. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

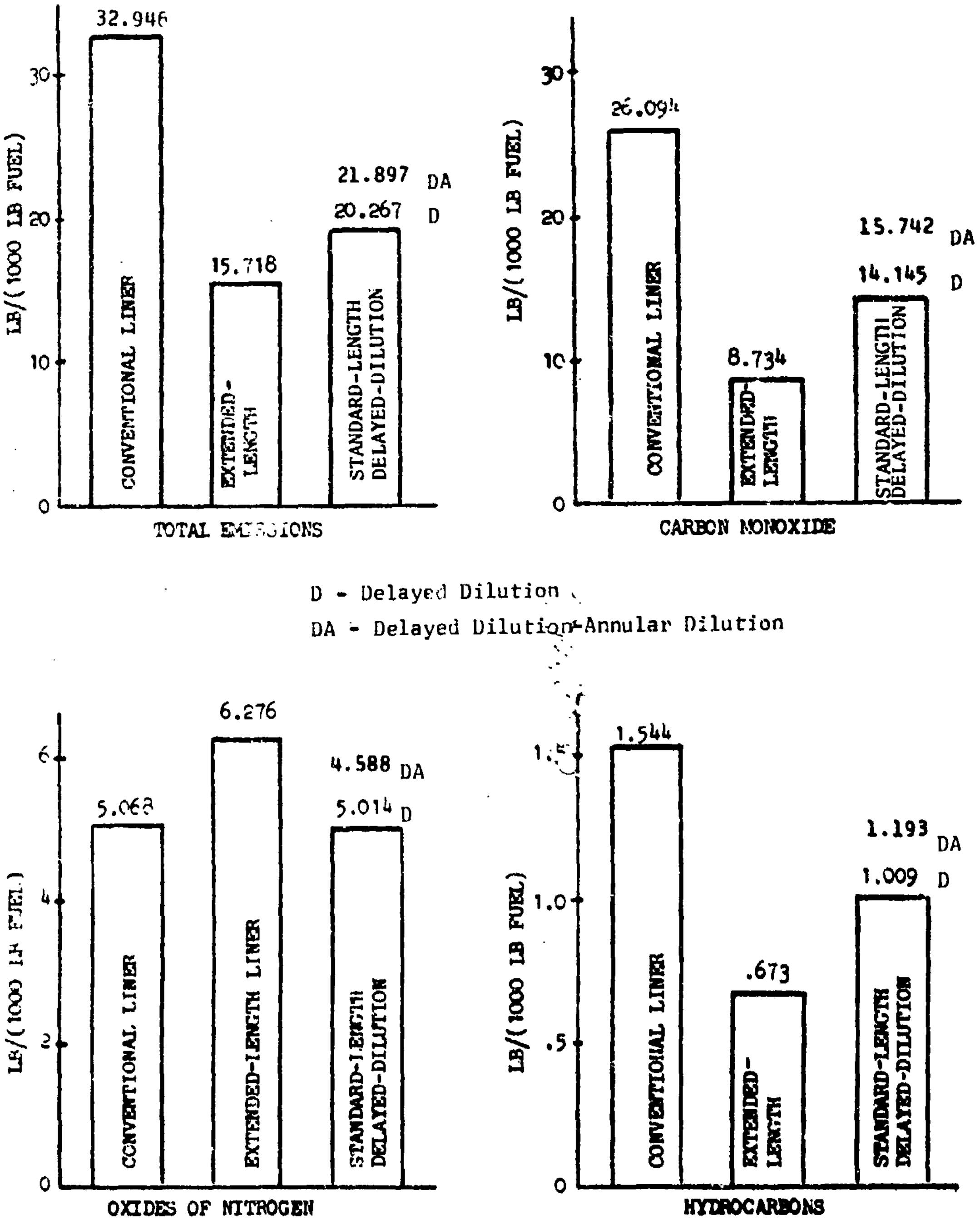


Figure 151. Nonregenerative T63-A-5A Emission Index Comparison Standard-Length, Delayed-Dilution and Standard-Length, Delayed-Dilution, Annular Dilution.

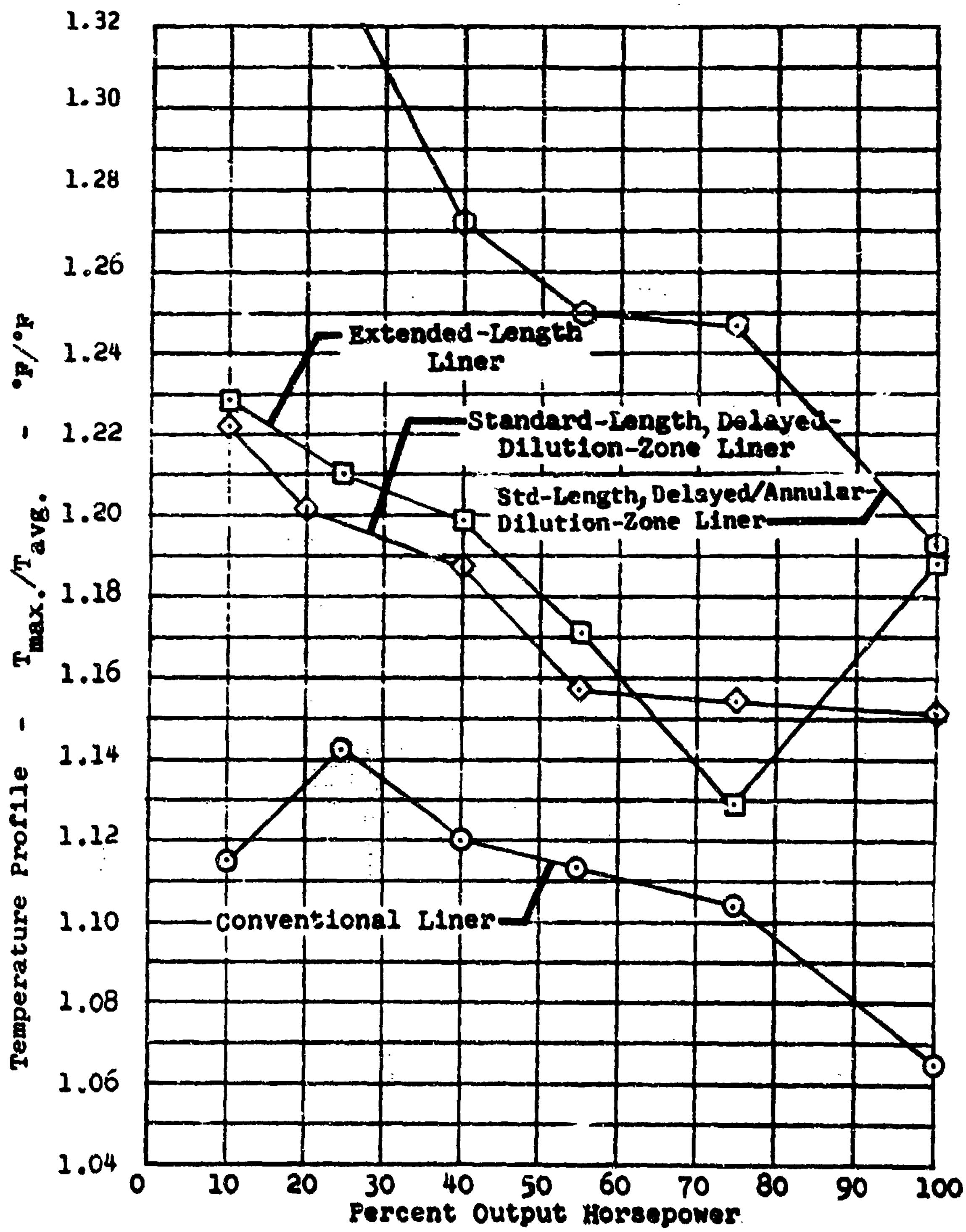


Figure 152. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Standard-Length, Delayed-Dilution-Zone Combustor, and T63 Baseline Combustors.

the emissions from the T63-A-5A combustor. This concept, if combined with other concepts, could probably meet the contract objective of 50% reduction in emissions. However, it should be incorporated without the annular dilution feature.

PREMIX-CUP/GASEOUS-FUEL COMBUSTOR

One of the potential concepts selected in the Task 2 studies was the "Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner." The concept was to mix the gaseous propane and primary-zone air in a premix cup. This mixture was then injected into the primary-zone through seven jet, flame-stabilization holes. Task 2 studies indicated that both CO and NO_x should decrease because:

- With premix/gaseous fuel, hot spots (zones) would be eliminated and the NO_x, CO, H/C, and smoke would be reduced.

- The jet-stirred primary-zone should provide a well-stirred primary-zone reaction chamber with rapid conversion to plug flow. These conditions, if achieved, are favorable for low NO_x and CO emissions.

- Previous experiments in Task 2 had shown that the extended length would significantly reduce CO and H/C emissions with a small increase in NO_x emissions.

The "Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner" was designed for the T63 nonregenerative combustor operating conditions tabulated in Table IV.

A completely redesigned primary zone and fuel injection system were fabricated to obtain the "Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner." The only part of the conventional T63 liner retained in the design was the dilution zone section. The "Extended-Length , Premix-Cup/Gaseous-Fuel Combustor Liner", as shown in Figure 153, has the following characteristics:

- The total length is 15.56 inches compared to 9.56 inches for the conventional T63 liner.

- The fuel injector system was designed for gaseous propane operation. As shown in Figure 153, the propane is injected from the fuel feed tube into the premix cup through 45 of 0.0468-inch diameter holes.

- The propane-air premix chamber was 3 inches in diameter x 3.15 inches in length.

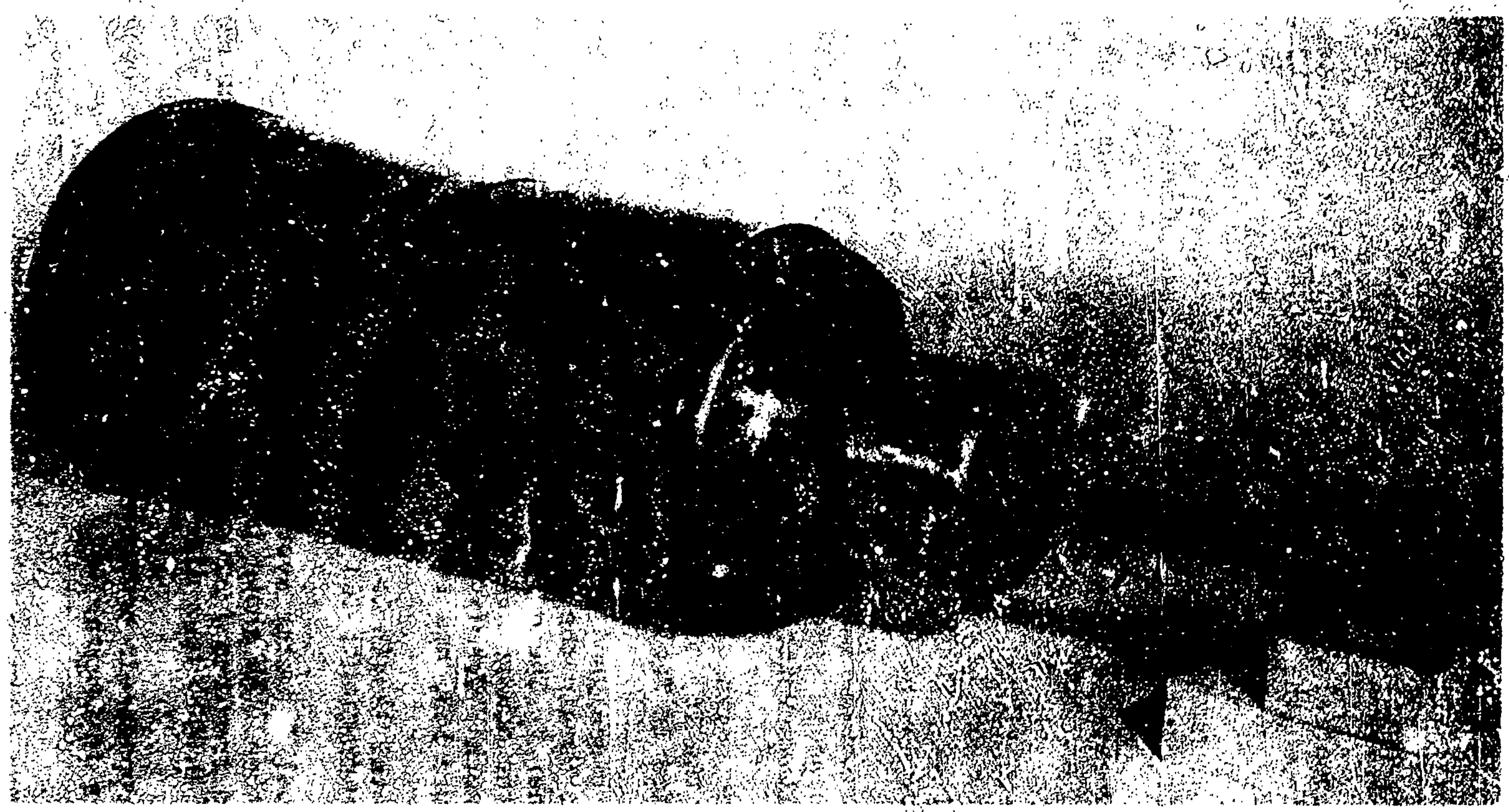


Figure 153. Preliminary Low-Emission, Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner - External View.

- The premixed propane-air was injected into the primary zone through seven jet holes of 0.687-inch diameter as shown in Figure 154. The expansion of these jets into the larger primary zone should provide the recirculation necessary for flame stabilization.

- The primary zone was convection cooled, as shown in Figure 153, instead of the conventional film cooling.

- The airflow distribution for the "Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner" was designed for the same flow distribution as the conventional T63 liner which is tabulated below:

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes.	26.3%
Second Cooling Step.	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above airflow distribution, the design equivalence ratio at maximum power for the T63 is 0.77.

The "Extended Length, Premix-Cup/Gaseous-Fuel Combustor Liner" was to be tested at the conditions tabulated in Table IV. The tests were conducted at steady-state conditions, in the DDA Combustion Research Laboratory, using gaseous propane fuel. Emission data were obtained at only Cycle Point 1 (Idle - 10% Power). An additional line of data, except for emission data, was obtained at Cycle Point 3 (75% Power Setting). The emission, pressure loss, and temperature profile results are summarized and compared with the "Conventional T63-A-5a Liner" and the "Extended-Length Liner" in Table LVII.

From the data comparison presented in Table LVII, the following conclusions are obvious:

- The emissions are extremely high.

- The temperature profile (T_{max}/T_{avg}) is excessive.

Therefore, there was no justification for conducting the experiments

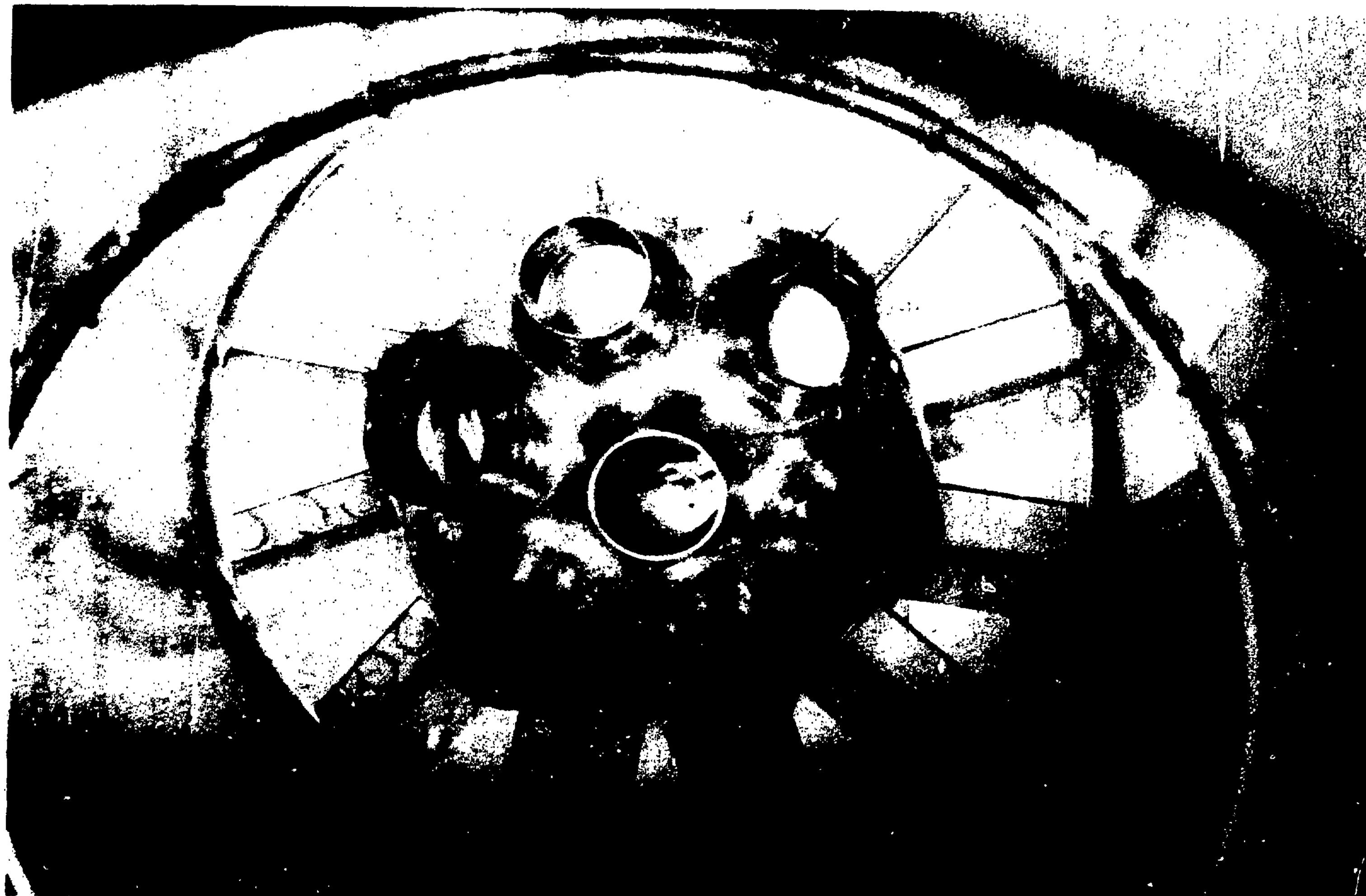


Figure 154. Internal, Upstream View of Preliminary Low-Emission, Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner.

TABLE LVII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL COMBUSTOR, (2) EXTENDED-LENGTH COMBUSTOR, AND (3) EXTENDED-LENGTH, PREMIX-CUP/GASEOUS-FUEL COMBUSTOR

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended Length-Premix Cup/Gaseous Fuel Liner		NO DATA TAKEN	NO DATA TAKEN	NO DATA TAKEN		NO DATA TAKEN
A. Emissions						
CO, (ppm)	1882.0				-	
H/C, (ppm)	1800.0				-	
NO_x, (On-Line, NDIR & NDUV) (ppm)	23.0				-	
NO_x, (Saltzman) (ppm)	-				-	
Smoke Number	-				-	
B. Pressure Loss (%)	6.59				6.40	
C. Temp. Profile (T_{max}/T_{Avg})	1.442				1.235	

at the other experimental cycle point conditions.

Cold-flow, aerodynamic tests with the liner showed that the problem is clearly the result of insufficient recirculation in the primary-zone. This is illustrated in Figures 155 and 156. Figure 155 shows the airflow pattern across the propane-air jets (see Figure 154), and Figure 156 shows the pattern between the jets. As shown in Figures 155 and 156, there was essentially no recirculation in the primary zone.

Inspection of the liner and combustor rig hardware after the test showed no apparent damage.

The "Extended-Length , Premix-Cup/Gaseous-Fuel Combustor Liner" did not provide the anticipated reduction in emissions because of inadequate primary-zone recirculation. As shown in Table LVII, its emission performance was worse than the conventional T63 combustor and the other combustors tested in this program.

The recommended method for increasing the recirculation is to use swirl. This was incorporated into a subsequent premix/swirl combustor concept which was designed to operate on either gaseous propane fuel or liquid JP-4 fuel by changing the fuel injector. However, as discussed in a later section in this appendix, only liquid fuel tests were conducted, as reported, because (1) subsequent progress indicated that program objectives could be met without the gaseous fuel data and (2) time and funding requirements limited the effort.

PLUG-FLOW/CANTED-PRIMARY COMBUSTOR

One of the potential concepts selected in the Task 2 studies was the "Extended-Length,- Plug-Flow/Canted-Primary Combustor Liner." The concept was to provide a well-mixed, stirred reactor zone with rapid conversion to plug flow. Task 2 studies indicated that both CO and NO_x should decrease because:

- A main source of NO_x and CO emissions in conventional combustors is the nonuniformity in temperature. High-temperature zones generate high NO_x and, conversely, low-temperature pockets cause high CO. Uniform temperature profile is ideal for minimum CO and NO emissions. The design goal was to provide well-mixed, stirred reactor conditions, which implies homogeneous composition and uniform temperature profile.

- Plug flow (one-dimensional flow) gives the most rapid "burn-out" (reaction rate) of the CO and H/C after ignition. Task 2 studies predicted significant CO reductions with plug flow. The same studies showed no effect (increase or decrease) on NO_x whether it was plug flow or perfectly stirred (zero-

Figure 155. Airflow Pattern Across the Propane/Air Feed Jets of the Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner.

Figure 156. Airflow Pattern Between the Propane/Air Feed Jets of the Extended-Length, Premix-Cup/Gaseous-Fuel Combustor Liner.

dimensional flow).

- Previous experiments in Task 2 had shown that the extended length would significantly reduce CO and H/C emissions with a small increase in NO_x emissions.

The "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" was designed for the T63 nonregenerative combustor operating conditions tabulated in Table IV.

A redesigned combustor liner was fabricated to obtain the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" shown in Figure 157. The only part of the conventional T63 liner retained in the design was the dome section and the conventional pressure-atomizing dual-orifice fuel injector. The redesigned liner had the following characteristics:

- The total length is 15.56 inches compared to 9.56 inches for the conventional T63 liner, as shown in Figure 158.

- Part of the liner, just downstream of the primary zone, was convection cooled instead of film cooled. The convection-cooled length was approximately 5.2 inches.

- The primary air was injected through twelve 0.5-inch I.D. tubes in a canted, upstream direction. The primary zone was sized to allow one recirculation loop in the primary. Recirculation was to be provided by the jet induced flow from the twelve primary air tubes.

- A contraction was installed at the primary-zone exit to cause rapid conversion from recirculation flow to plug flow.

- As shown in Figure 158, the conventional liner trim and dilution holes were combined into a single row of dilution holes. This row of holes was located far enough downstream to allow sufficient residence time to consume the CO, H/C, and C in the intermediate zone between the primary and dilution holes.

- The airflow distribution for the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" was designed to be the same as that of the conventional T63 liner, which is tabulated below:

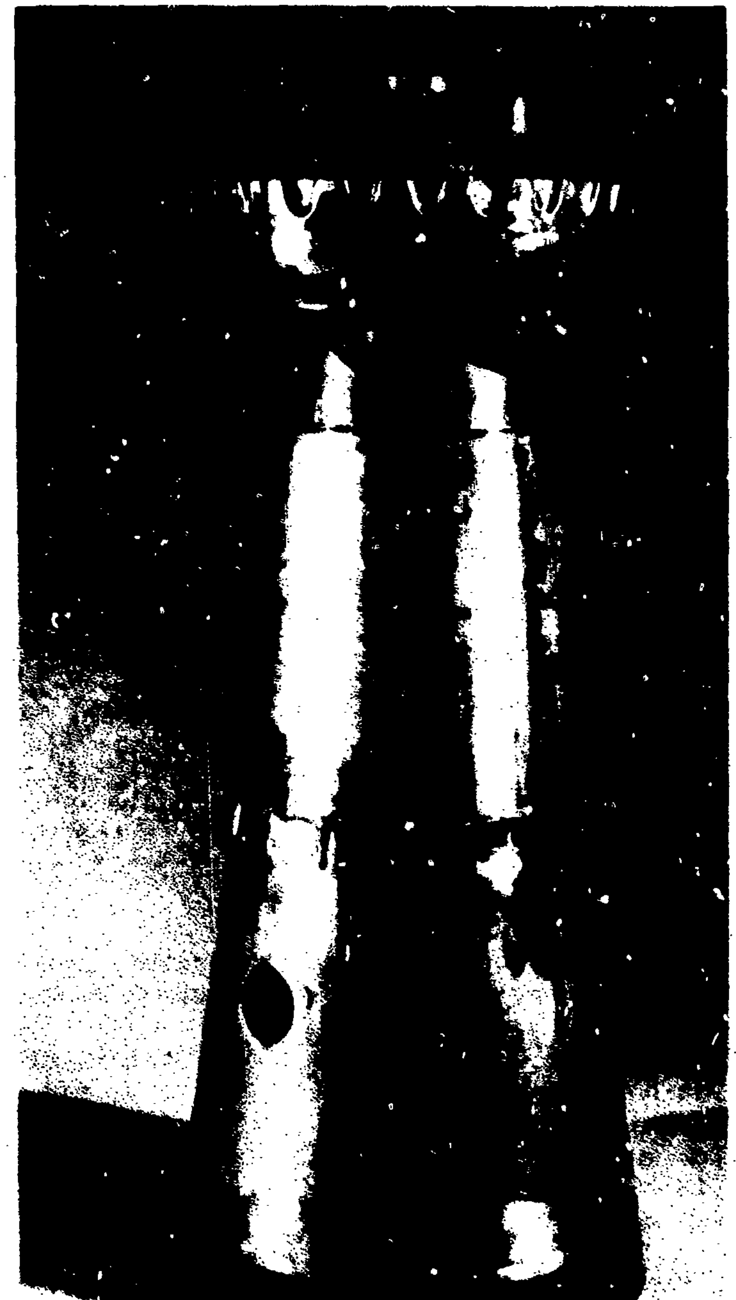


Figure 157. Preliminary Low-Emission Extended-Length, Plug-Flow/Canted-Primary Combustor Liner - Initial Design.

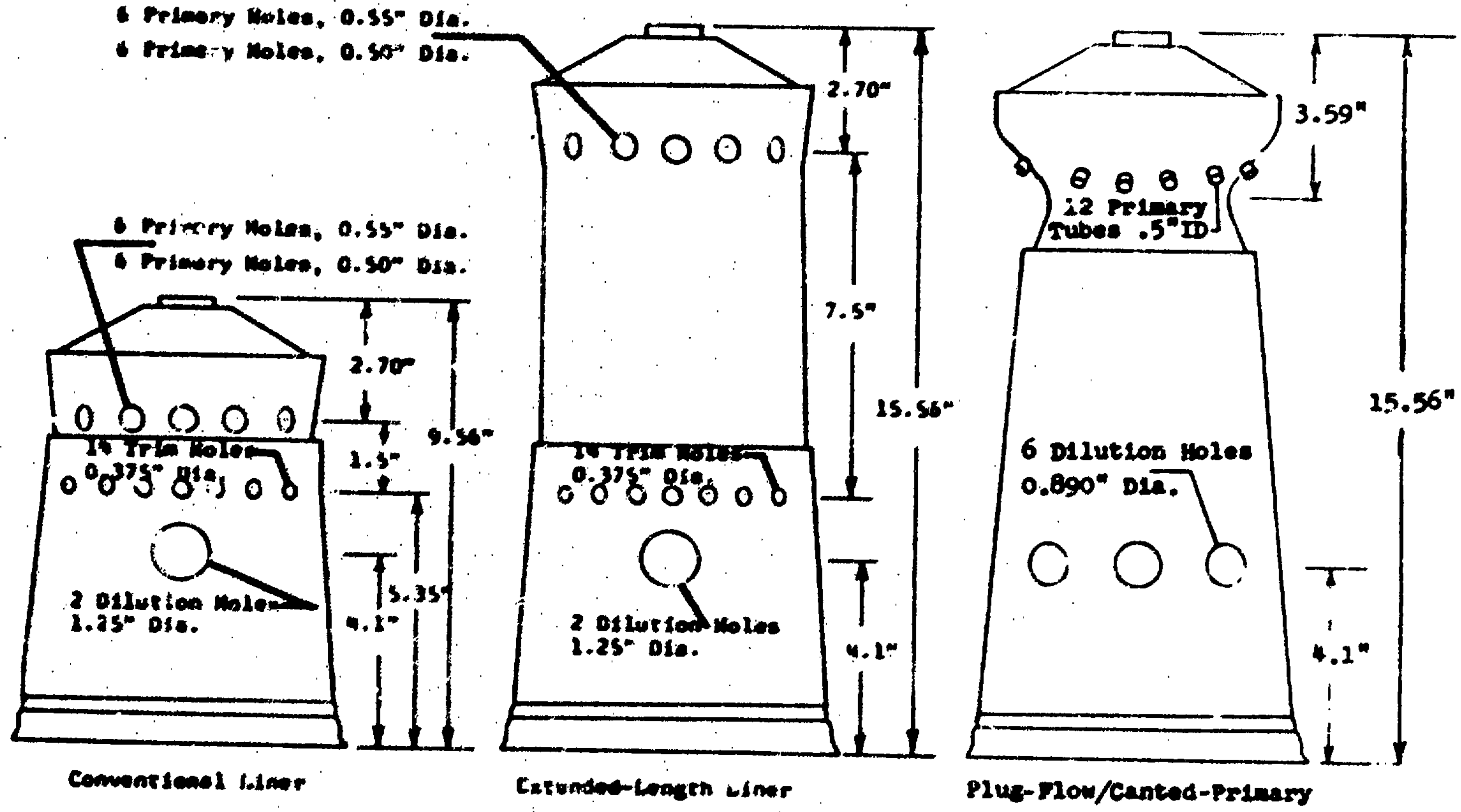


Figure 158. Hole Pattern and Siz. Comparison of Liners.

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes.	26.3%
Second Cooling Step.	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above airflow distribution, the design equivalence ratio at maximum power for the T63 is 0.77.

The above described, initial design "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" was cold-flow tested and hot-flow tested at the T63 nonregenerative combustor conditions outlined in Table IV. The data indicated inadequate recirculation in the primary zone. Therefore,the combustor was redesigned into Modification "A" to improve the recirculation. Modification "A", as shown in Figure 159, incorporated the following changes:

- The number of primary air feed tubes was reduced from twelve to eight.
- The reduced primary hole area and the conventional dome cooling flow area were put into swirl air in the dome.

In addition to the design changes to improve recirculation, the primary zone, film coolant air was eliminated. This air was also added as swirl air in the combustor dome.

The primary zone/dilution airflow split in the Modification "A" was maintained the same as in the initial design and the conventional T63 combustor liners.

The initial design and Modification "A" of the "Extended-Length. Plug-Flow/Canted-Primary Combustor Liner" were tested at the conditions tabulated in Table IV. The tests were conducted in the DDA Combustion Research Laboratory using JP-4 fuel. The experimental results for the initial design and Modification "A" are discussed in the following subsections.

<u>Initial Design - Experimental Results</u>

The experimental data from the initial design (Figure 157) are compared with the emission data from the "T63 Conventional Combustor" and the "Extended-Length Combustor" in Table LVIII and Figures 160 through 163. The results show that, except

Figure 159. Preliminary Low-Emission Extended-Length, Plug-Flow/ Canted-Primary Combustor Liner - Modification "A".

TABLE LVIII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, AND (3) PLUG-FLOW/CANTED-PRIMARY, EXTENDED-LENGTH LINER - INITIAL DESIGN.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV)(ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Plug Flow/Canted Primary Extended Length Liner						
A. Emissions						
CO, (ppm)	1160.8	786.1	587.4	376.0	191.9	56.4
H/C, (ppm)	260.0	120.0	57.0	22.0	4.6	1.2
NO_x, (On-Line, NDIR & NDUV) (ppm)	21.0	27.0	27.0	40.5	67.0	110.0
NO_x, (Saltzman) (ppm)	14.1	25.2	34.8	49.0	76.7	124.9
Smoke Number	22.54	29.02	24.07	29.66	28.03	24.25
B. Pressure Loss (%)	5.56	5.52	5.42	5.58	5.41	4.95
C. Temp. Profile (T_{max}/T_{Avg})	1.364	1.308	1.297	1.238	1.200	1.194

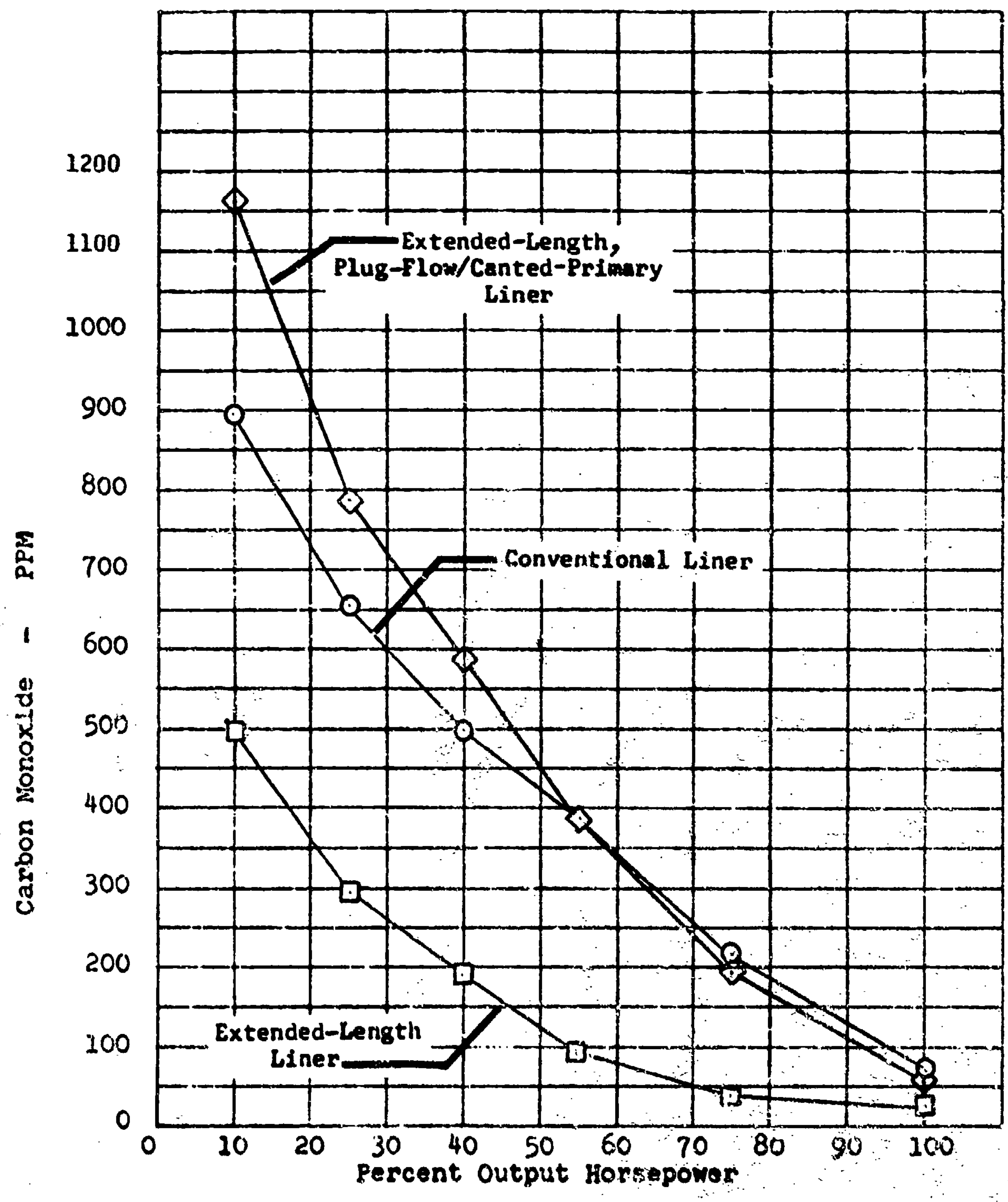


Figure 160. Nonregenerative T63-A-5A Combustor Carbon Monoxide Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor and T63 Baseline Combustors.

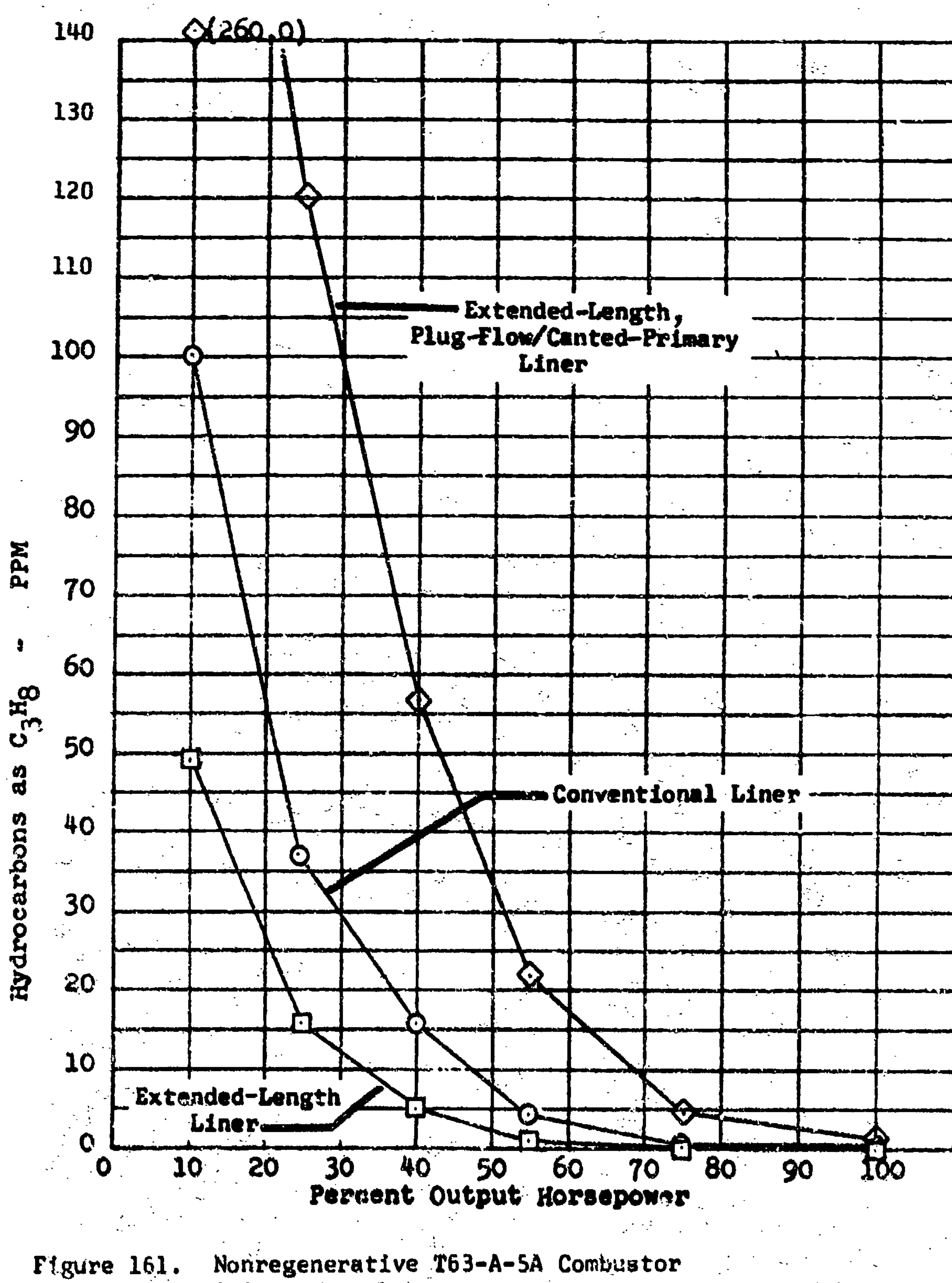


Figure 161. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Date Comparison for Extended-Length, Plug-Flow/Canted-Primary and T63 Baseline Combustors.

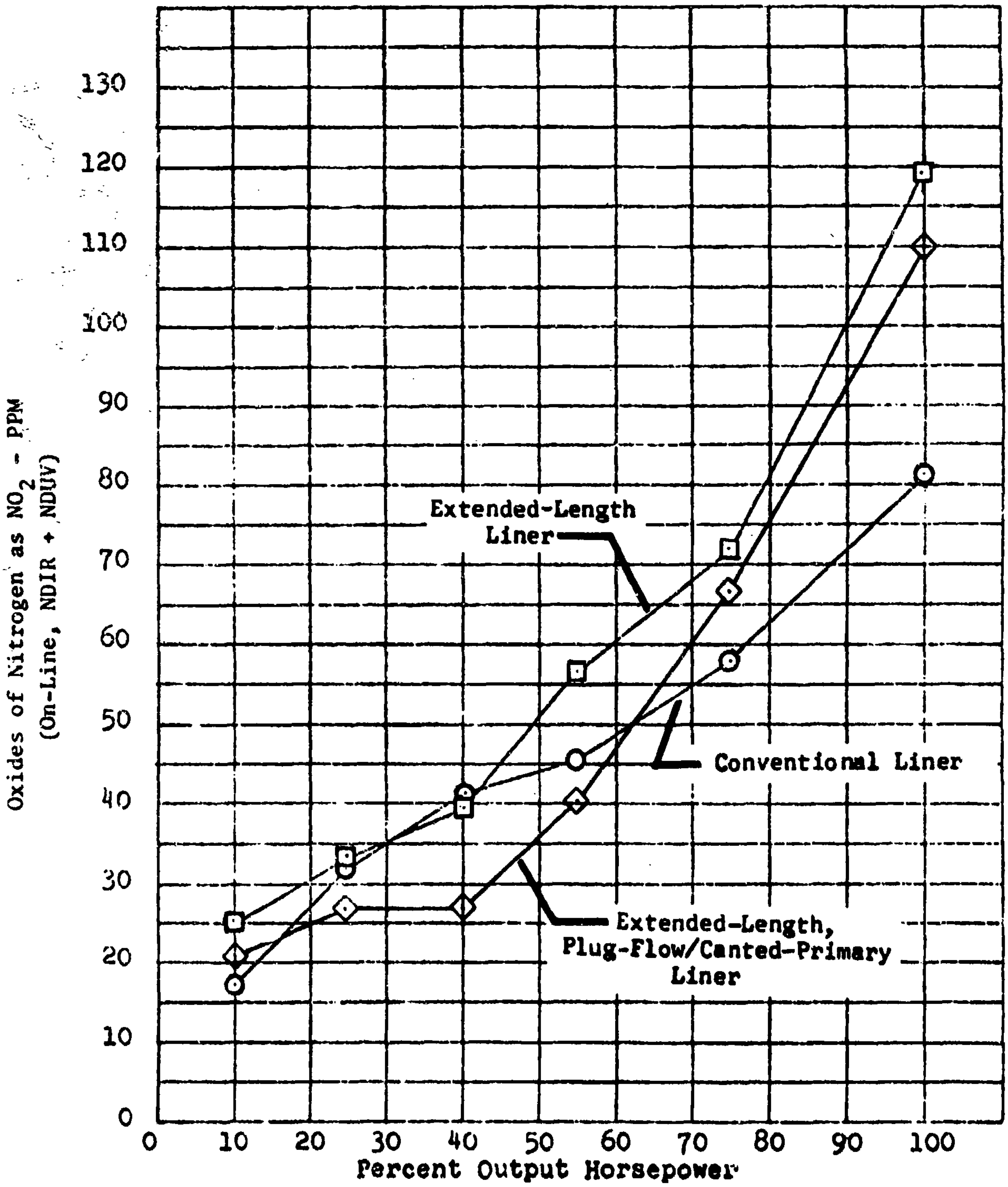


Figure 162. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor and Baseline T63 Combustors.

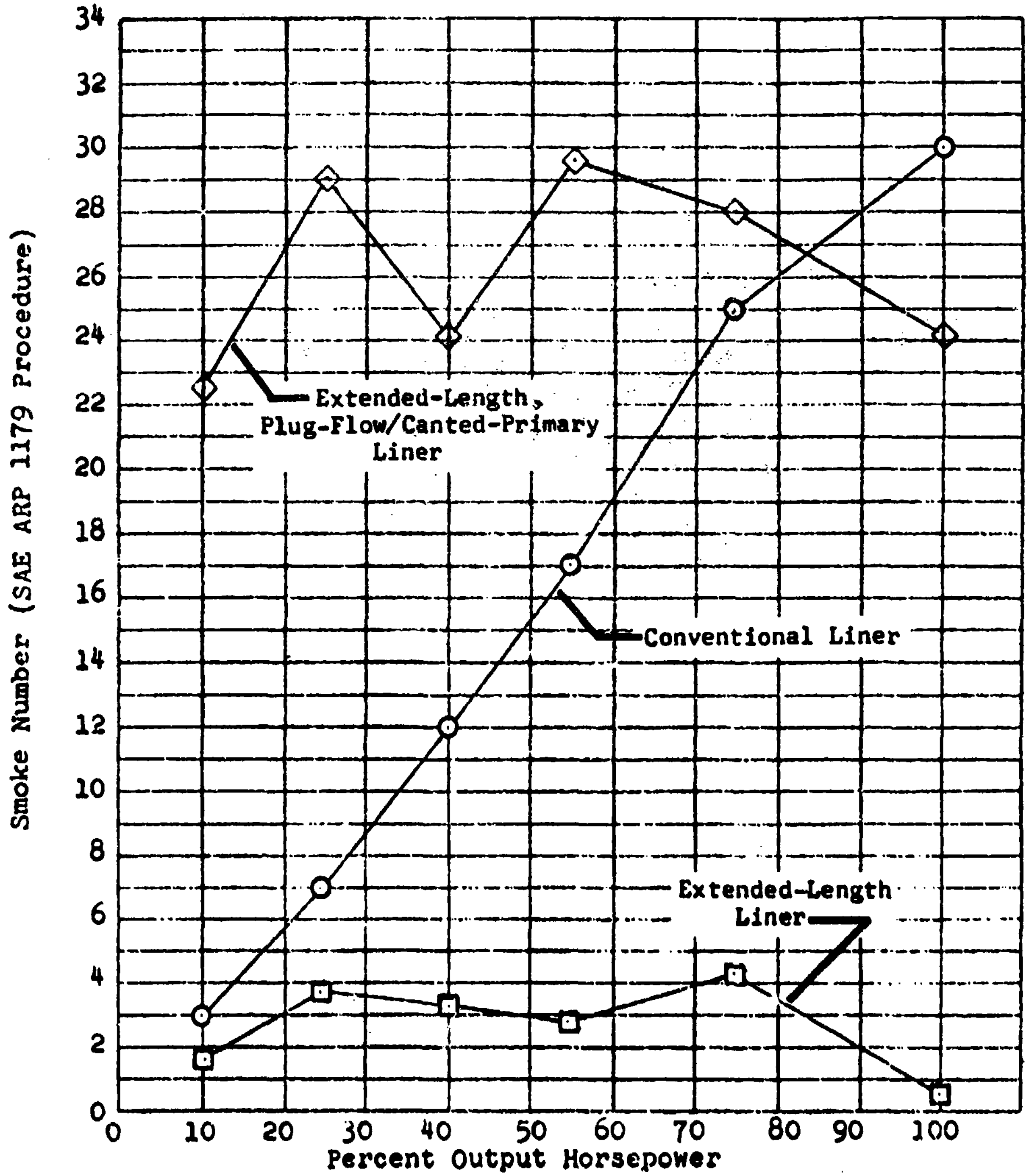


Figure 163. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor and T63 Baseline Combustors.

for limited cases, the emissions from the initial design were greater than from either the "T63 Conventional Liner" or the "Extended-Length Combustor." The emission data were used to calculate the emission index as presented in Figure 164 and Table XLVI.

For the selected LOH duty cycle, the total emission index for the initial design of the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" was 17% higher than the "T63 Conventional Liner" as shown in Table XLVI. This table also shows that the CO and H/C emissions were higher than the "T63 Conventional Combustor Liner" and that NO_x was approximately the same. Compared with the "Extended-Length Liner" (which was the same length) the total emissions from the initial design of the "Extended Length, Plug-Flow/Canted-Primary Combustor Liner" was approximately 2.4 times greater. However, there was approximately a 20% reduction in NO_x emissions.

The temperature profile (T_{max}/T_{avg}) for the initial design of the "Extended Length, Plug-Flow/Canted-Primary Combustor Liner" was worse than either the "T63 Conventional Liner" or the "Extended-Length Liner", as shown in Figure 165.

In order to qualitatively assess the problem, cold airflow tests were made with the initial design. These tests clearly showed that the problem was inadequate recirculation in the primary zone. The plug flow section seemed to be operating in the desired manner. Due to the close spacing in the primary jets, as shown in Figure 157, it appeared that there was not sufficient flow area for the recirculation loop to get out of the primary. In fact, the cold-flow test showed that less than 50% of the primary air was going into the primary section. Therefore, cold-flow tests were conducted with 6 of the 12 primary holes plugged. The cold flow results indicated some improvement, however, only about 50% of the intended primary air was entering the primary zone. Therefore, a major modification was made to the liner as described previously.

Modification "A" - Experimental Results

Cold flow experiments were conducted with the modified liner shown in Figure 159. Several interesting characteristics were:

- From some of the primary jets, 100% of the air was entering the primary section, whereas only 50% of the air from other jets was entering the primary section.

- A considerable amount of the dilution air is partially entrained in the upstream direction, whereas in the initial design all the dilution air was flowing downstream. This

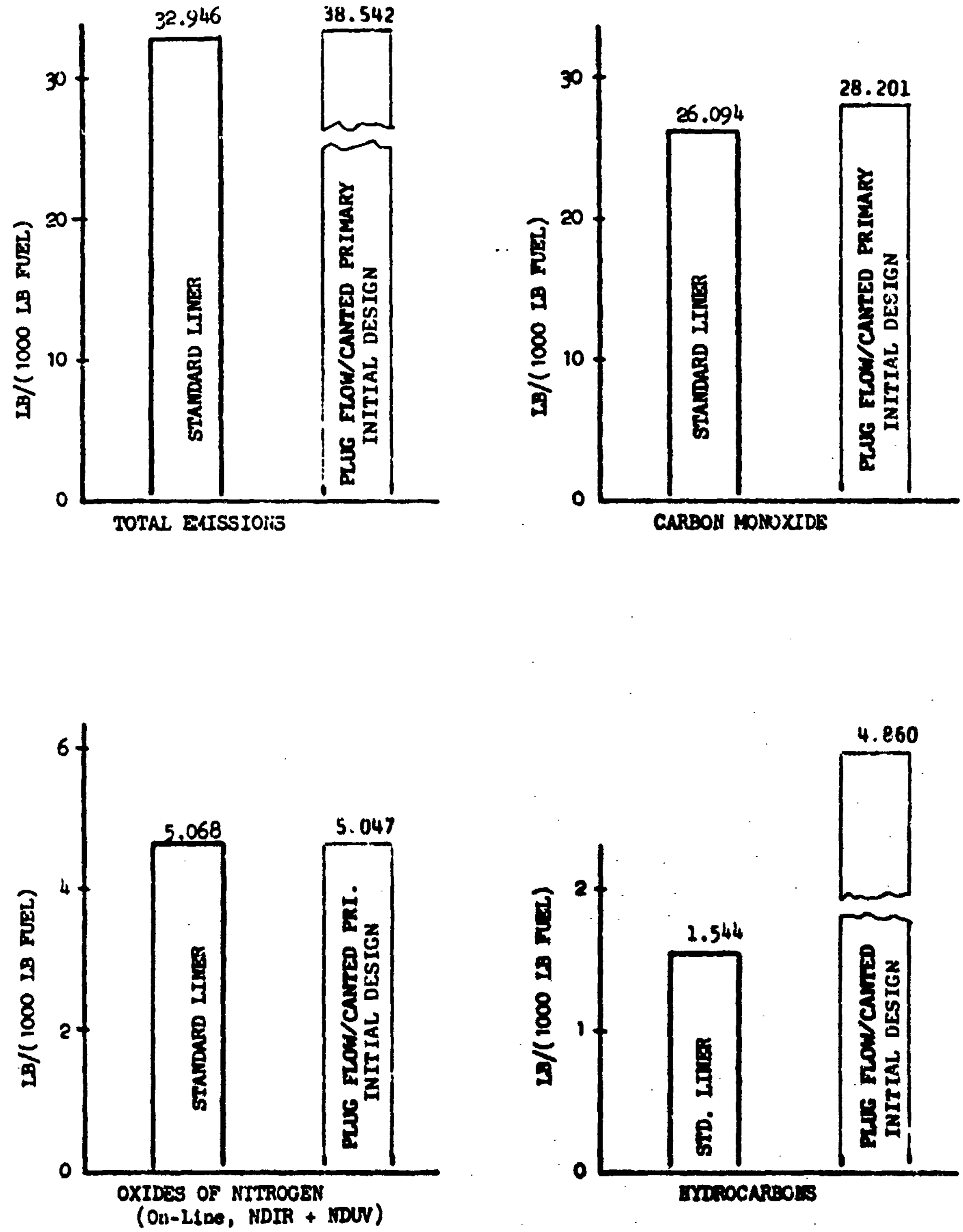


Figure 164. Nonregenerative T63-A-5A Emission Index Comparison Extended-Length, Plug-Flow/Canted-Primary Initial Design.

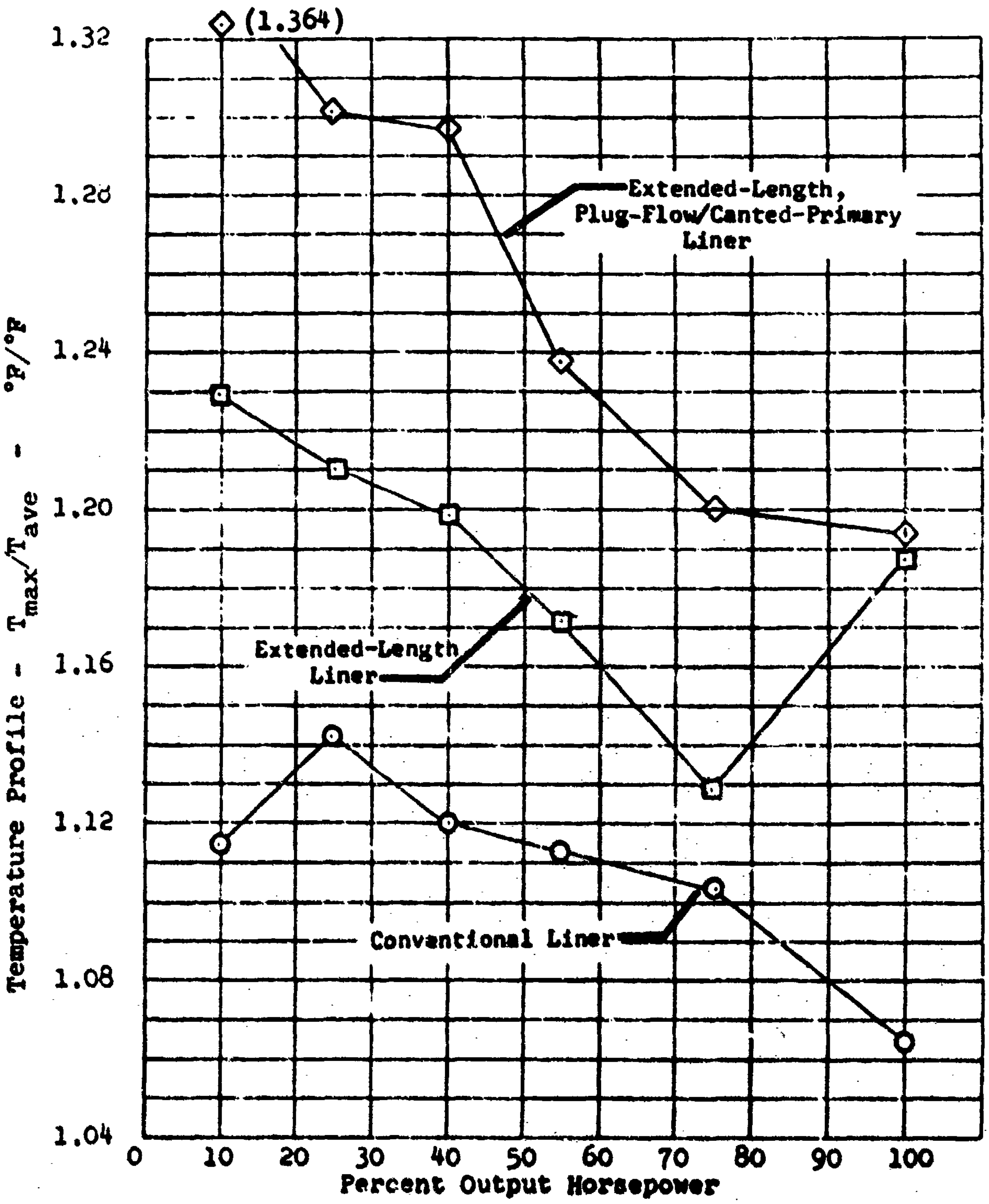


Figure 165. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor and T63 Baseline Combustors.

upstream entrainment is undoubtedly due to the effect of the dome swirl added in Modification "A".

- The apparent distortion might be "real", but it is difficult to resolve without hot-wire anemometer experiments because of the swirl components in the Modification "A" combustor liner. The cold-flow plate tests are always subject to interpretation due to the flow disturbance induced by the plate and the boundary layer flow of the plate itself. These effects are even more difficult to discern when strong swirl is present such as in Modification "A".

The Modification "A" combustor liner was hot-flow tested at the simulated T63 combustor conditions tabulated in Table IV. Emission results for the Modification "A" combustor are compared with the "T63 Conventional Liner" and "Extended-Length Liner" in Table LIX and Figures 166 through 169. The emission index values were calculated for a LOH duty cycle, and the results are presented in Table XLVI. The total emissions from the Modification "A" combustor were approximately 37% less than the "T63 Conventional Liner" but slightly higher than the "Extended-Length Liner", which was the same length as Modification "A". The emissions from the Modification "A" combustor were much less than from the initial design of the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner," but it would require considerably more development to show significant reductions in emissions compared to the conventional "Extended-Length Liner." The biggest pollutant problem would appear to be particulate emissions, as shown by the smoke data in Figure 169. Large deposits of carbon were also found in the "dead-spaces" of the dome after the experiments. This is a common problem found in all swirl system dead-spaces.

An outstanding performance feature of the Modification "A" design of the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" was the exceptionally good temperature profile (T_{max}/T_{avg}), as shown in Figure 170. This is probably due to the swirl flow pattern in the combustor liner. The temperature profile was better than with any other combustor tested in this program.

Neither the Initial Design or Modification "A" of the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" provided the anticipated reduction in total emissions. However, both liners demonstrated a moderate reduction in NO_x compared to the same size conventional liner ("Extended-Length Liner"). Modification "A" did have significantly lower (approximately 50%) emissions than the Initial Design. Further development of the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" would probably provide significantly lower emissions. Recommended areas for further study are:

TABLE LIX. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, AND (3) PLUG-FLOW/CANTED-PRIMARY SWIRL DOME LINER, MODIFICATION "A"

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.0
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.0
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	195.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.54
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Plug-Flow/Canted-Primary Swirl Dome Modification "A"						
A. Emissions						
CO, (ppm)	556.1	349.5	211.9	150.8	103.0	59.9
H/C, (ppm)	63.0	19.2	6.0	1.1	.9	.9
NO_x, (On-Line, NDIR & NDUV) (ppm)	21.0	32.5	42.5	51.5	71.5	101.5
NO_x, (Saltzman) (ppm)	26.8	39.4	51.2	65.6	89.3	115.3
Smoke Number	35.38	43.75	44.07	50.50	56.18	62.94
B. Pressure Loss (%)	5.98	5.50	5.46	5.90	5.43	5.27
C. Temp. Profile (T_{max}/T_{Avg})	1.095	1.093	1.108	1.095	1.088	1.087

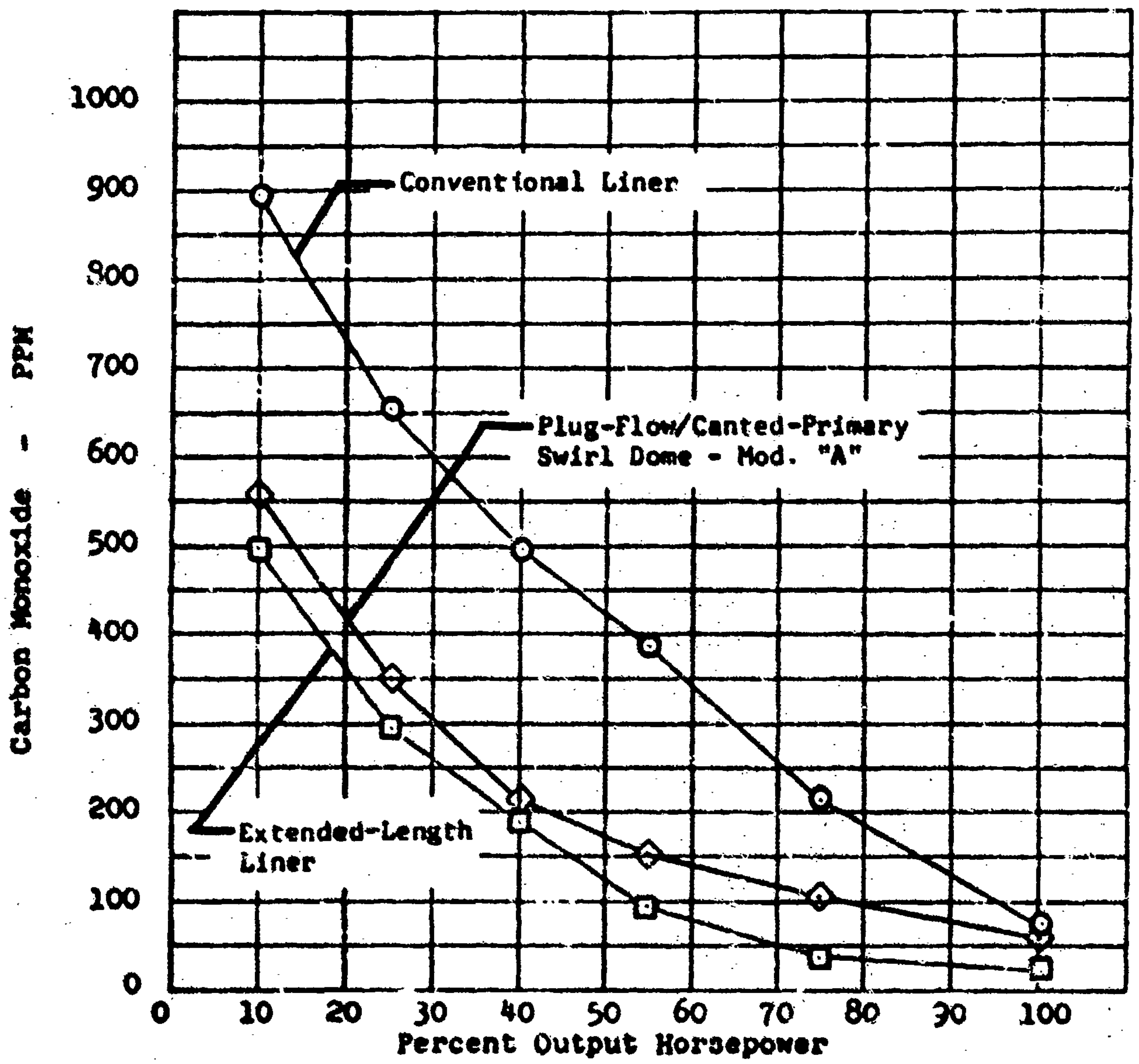


Figure 166. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emissions Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor Modification "A" and T63 Baseline Combustors.

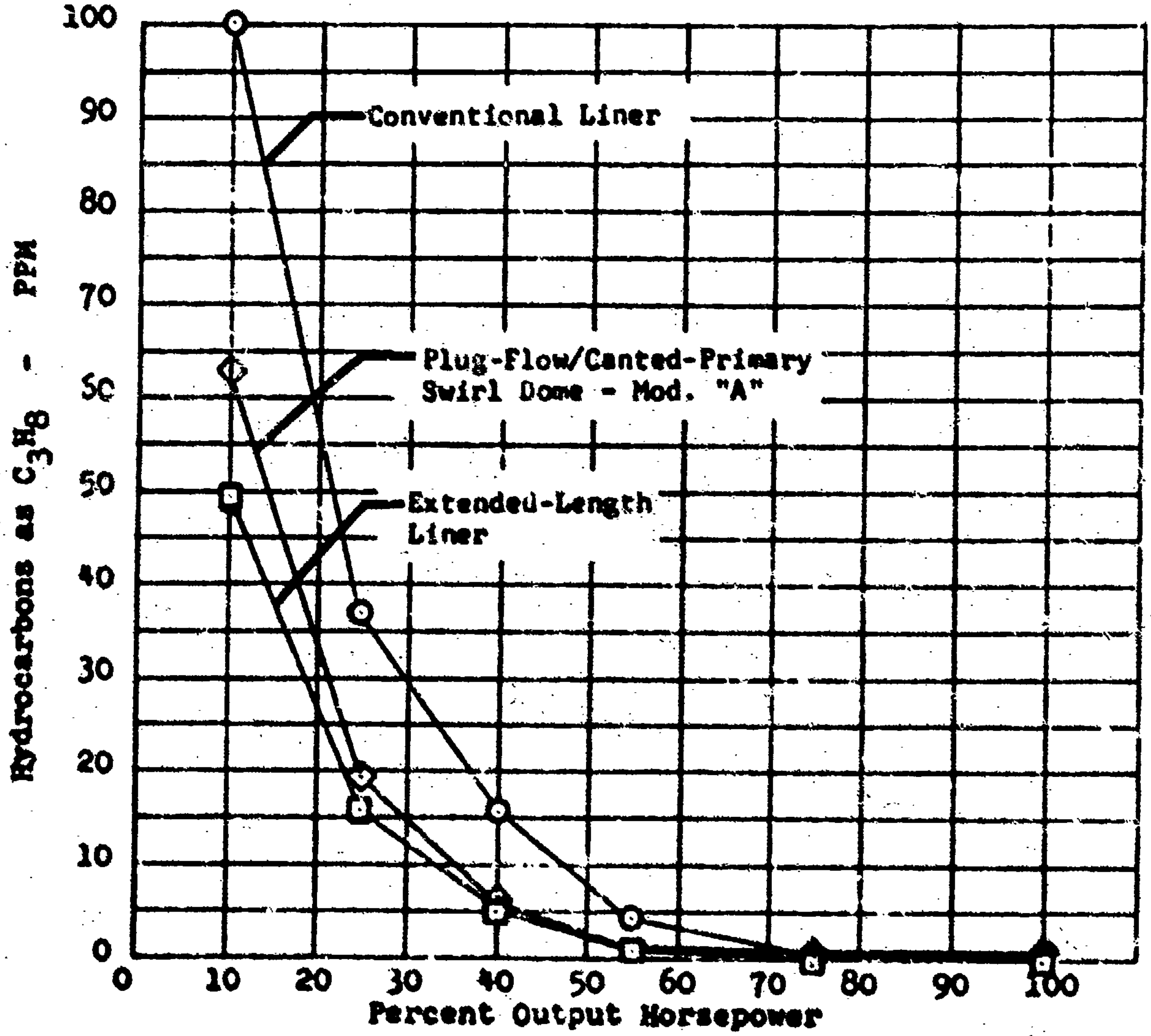


Figure 167. Nonregenerative T63-A-5A Combustor Hydrocarbon Emissions Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor Modification "A" and T63 Baseline Combustors.

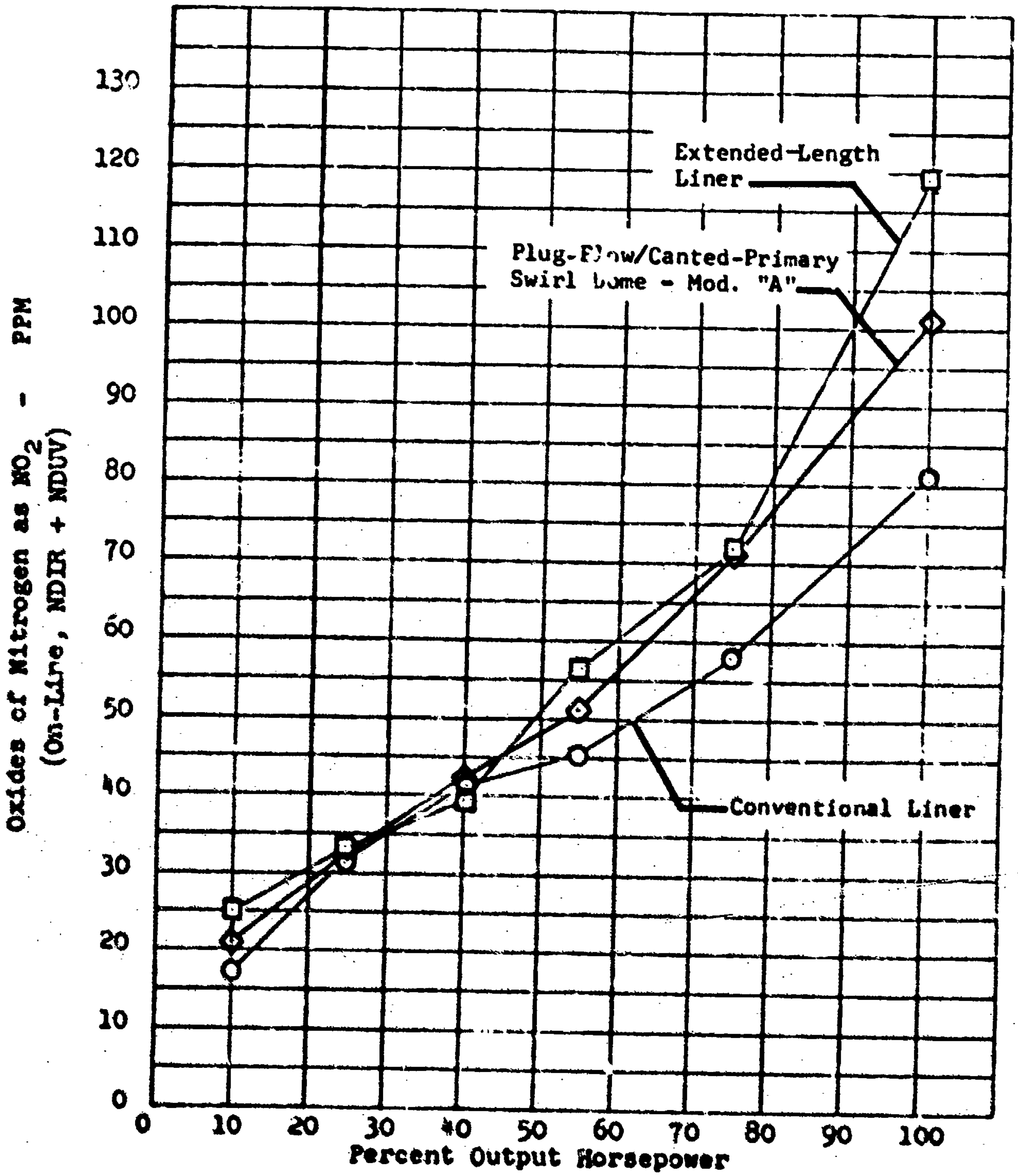


Figure 168. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emissions Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor Modification "A" and T63 Baseline Combustors.

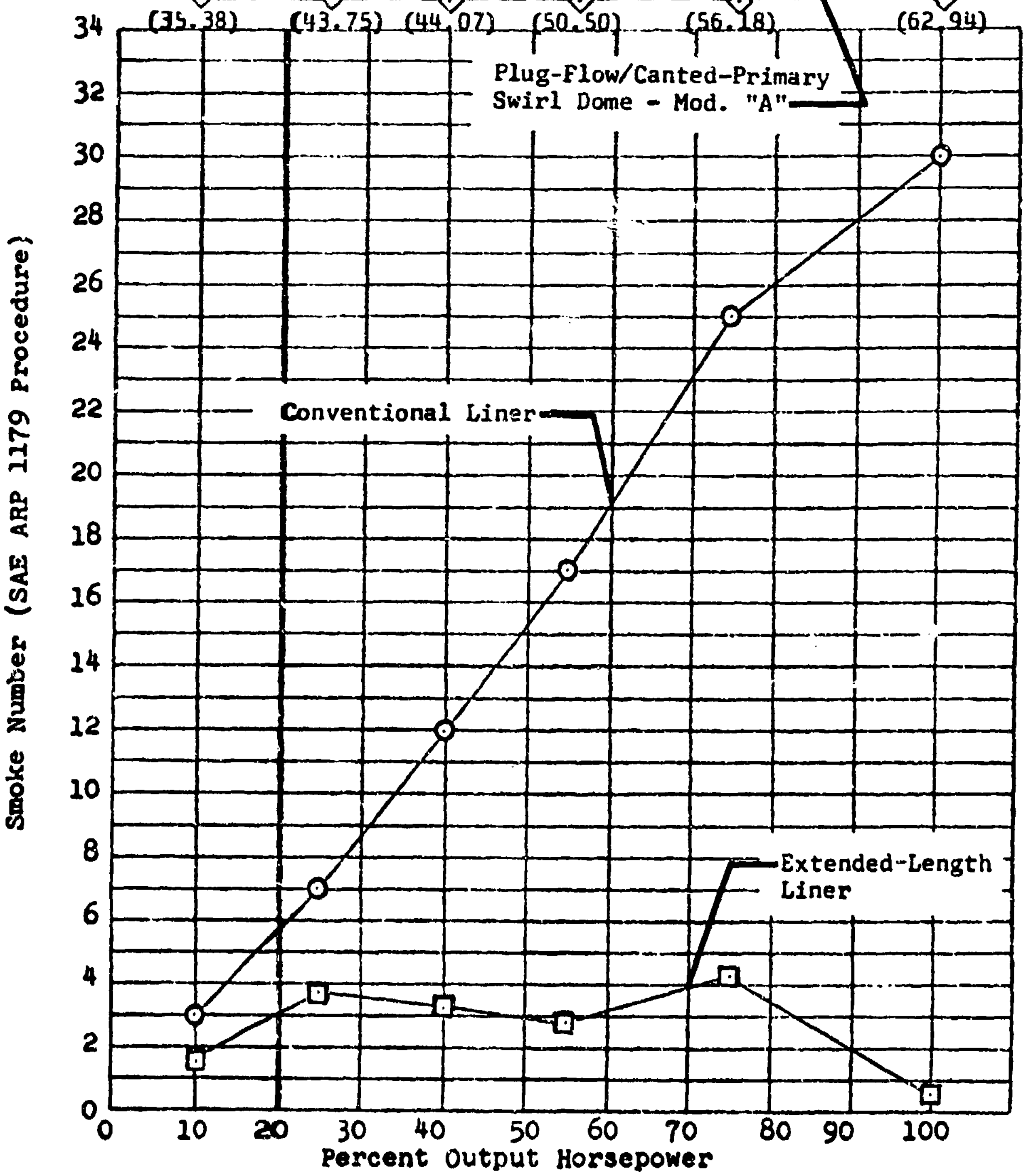


Figure 169. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor Modification "A" and T63 Baseline Combustors.

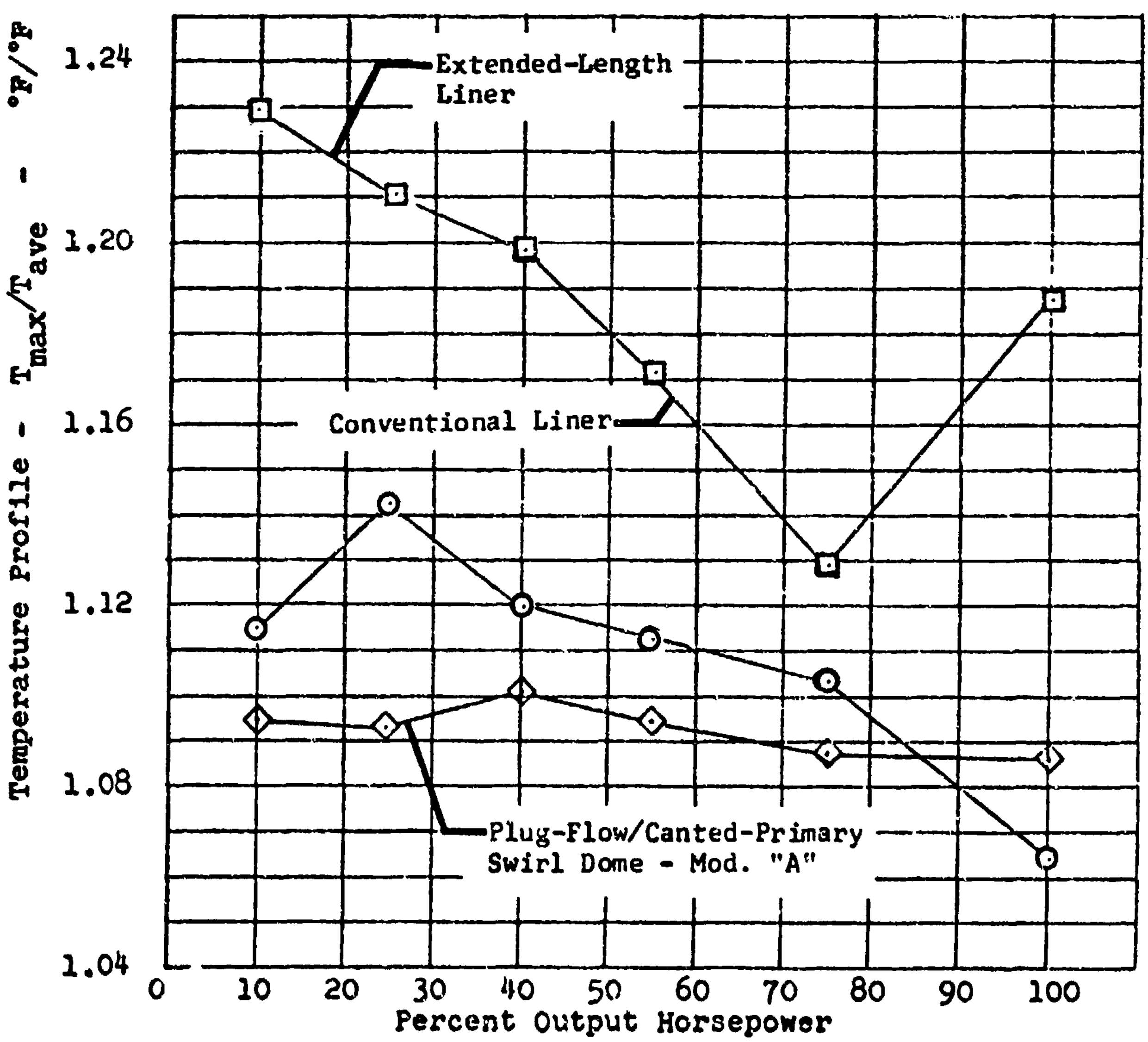


Figure 170. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Plug-Flow/Canted-Primary Combustor Modification "A" and T63 Baseline Combustors.

- Increase the primary-zone volume.
- Increase the primary-zone recirculation.
- Eliminate all dead-spaces in the dome to reduce the carbon buildup.

Further studies of the "Extended-Length, Plug-Flow/Canted-Primary Combustor Liner" were not conducted because the program objective in the early part of Task 3 was to obtain only enough experimental data to evaluate the potential of the many different concepts. As shown in Table XLVI, Modification "A" provided improvement in NO_x performance (compared to the same residence time liner), but other concepts subsequently tested demonstrated greater potential for emission reduction.

TANGENTIAL-SWIRL COMBUSTOR

One of the potential concepts selected from Task 2 studies was the "Extended-Length, Tangential-Swirl Liner." The concept was to replace the existing primary holes with a set of sixteen tangential swirl louvers discharging upstream. The swirl louvers were fabricated in a 6-inch cylindrical section added between the dome and the first film cooling annulus. Task 2 studies indicated that NO_x should decrease because:

- Primary zone swirl should improve the mixedness and reduce the local hot-spot temperatures in the primary-zone, thus reducing the concentrations of the NO_x formed.
- The primary-zone recirculation should be improved, thus increasing flame stability.
- The intermediate temperature zone (distance from primary holes to dilution holes) residence time increases. Thus, additional time is provided to consume the CO, C_xH_y, and carbon.

The modifications made to the conventional T63-A-5A liner to obtain an "Extended-Length, Tangential-Swirl Liner" were:

- Add constant diameter, 6-inch-length section between the dome and the first cooling annulus.
- Close original row of primary holes.
- Add two rows of swirl louvers .30 inch wide by 1.00 inch long, eight per row, inclined upstream at a 45-degree angle, and arranged in a helical pattern.

o Add a convection cooling shell between the second row of louvers and the first film cooling annulus, connected to and feeding the first film cooling annulus.

The hole patterns and important axial dimensions for the "Conventional Liner," the "Extended-Length Liner," and the "Extended-Length, Tangential-Swirl Liner" are shown in Figure 171. All three liners had the same airflow area split as tabulated below:

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes or Louvers	26.3%
Second Cooling Step.	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above calculated flow splits, the primary-zone equivalence ratio at T63 maximum power is 0.77 for all three liners. This ratio is based on the primary zone air being supplied only by the dome holes and the primary holes or louvers. The first cooling step is assumed to mix with the reaction gases further downstream.

The "Extended-Length, Tangential-Swirl Liner" which was fabricated for test is shown in Figures 172 and 173.

The "Extended-Length, Tangential-Swirl Liner" was tested in a T63 combustor rig at two of the nonregenerative T63 combustor conditions tabulated in Table IV. The emission, pressure loss, and temperature profile results are summarized and compared with the "Conventional T63-A-5A Liner" and the "Extended-Length Liner" in Table LX. All three liners were tested with the conventional T63 pressure atomizing fuel injector and JP-4 fuel. As shown in Table LX, data were not taken for the "Extended-Length, Tangential-Swirl Liner" at cycle points 2, 3, 4, and 5 because it was obvious from the flame pattern distortion and the results of the on-line CO and C_xH_y instrumentation for the first two data points that this combustor liner could not produce emissions as low as the "Conventional Liner," let alone 50% lower emissions. Also, the extremely poor exhaust temperature profile would have resulted in localized overheating and combustor failure at the higher operating points.

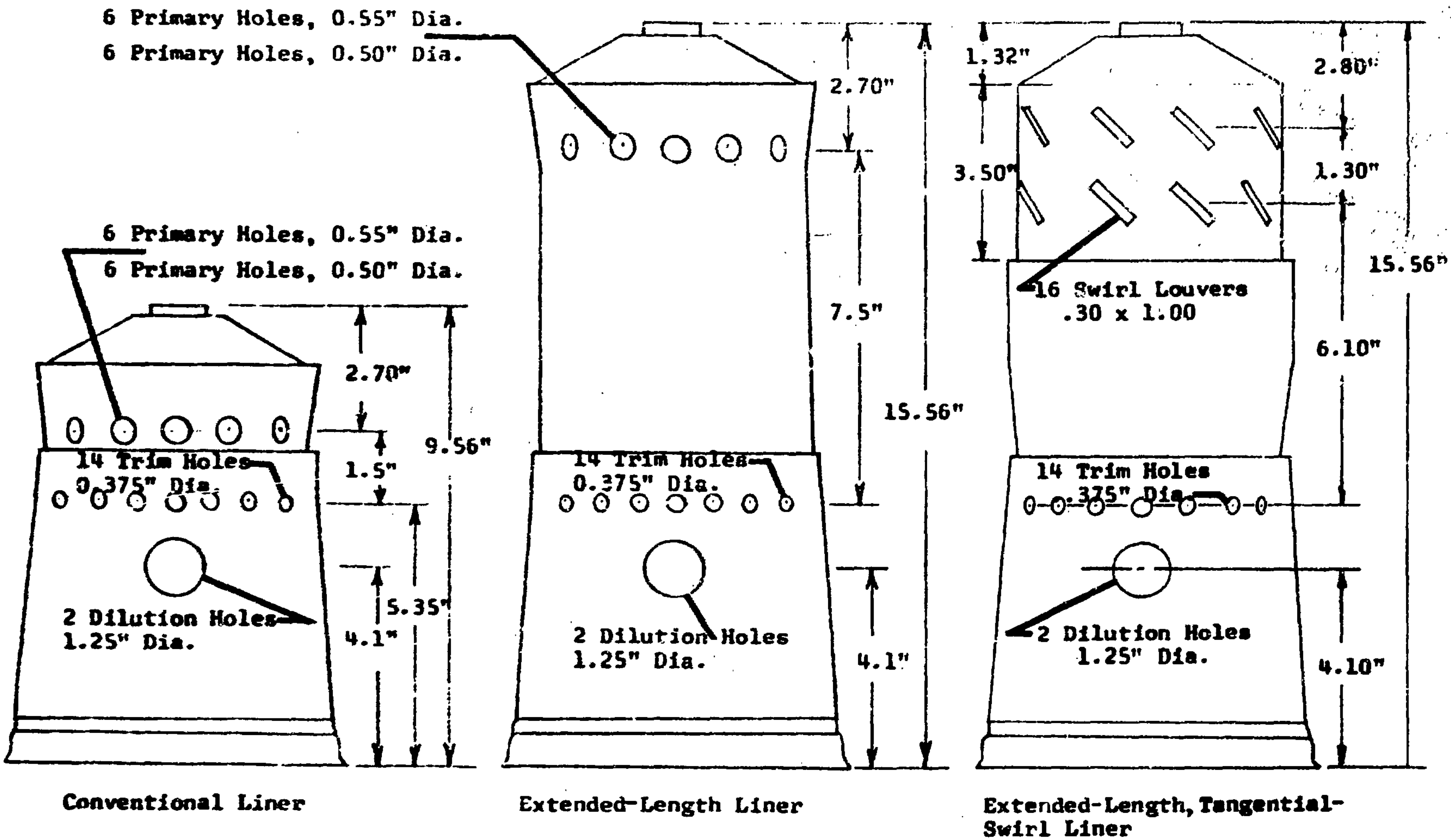


Figure 171. Hole Pattern and Size Comparison of Liners.

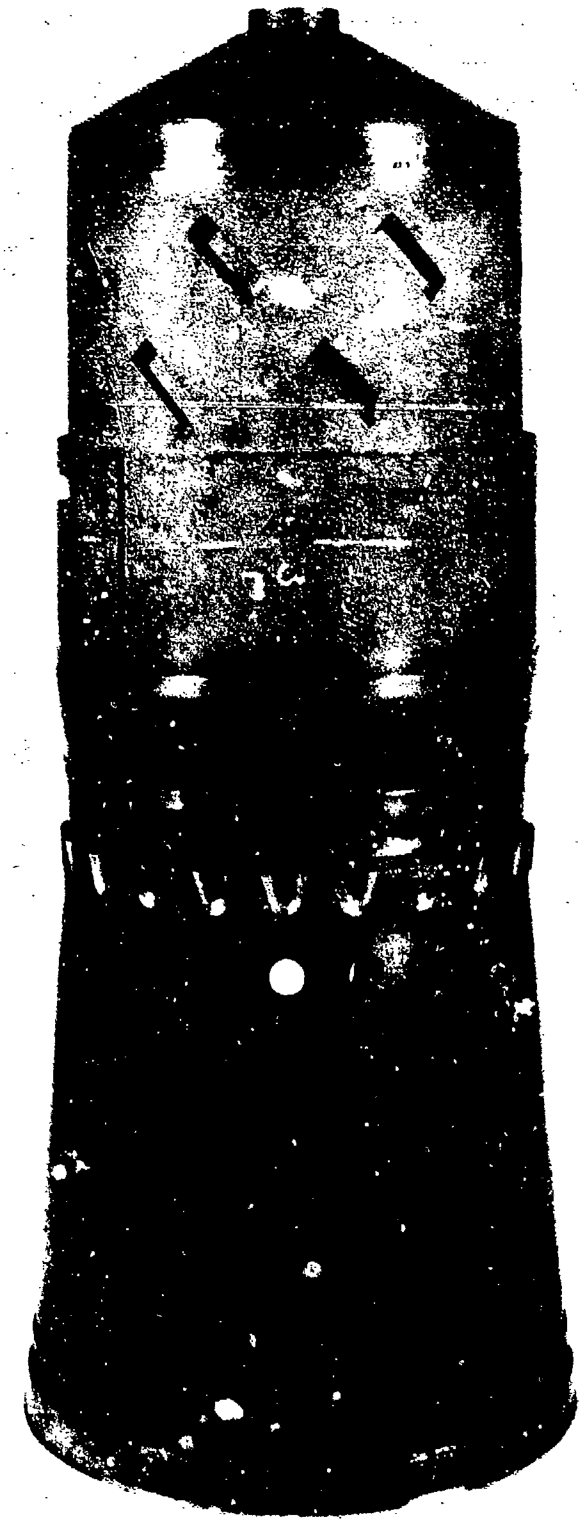


Figure 172. Preliminary Low-Emission, Extended-Length, Tangential-Swirl Liner.

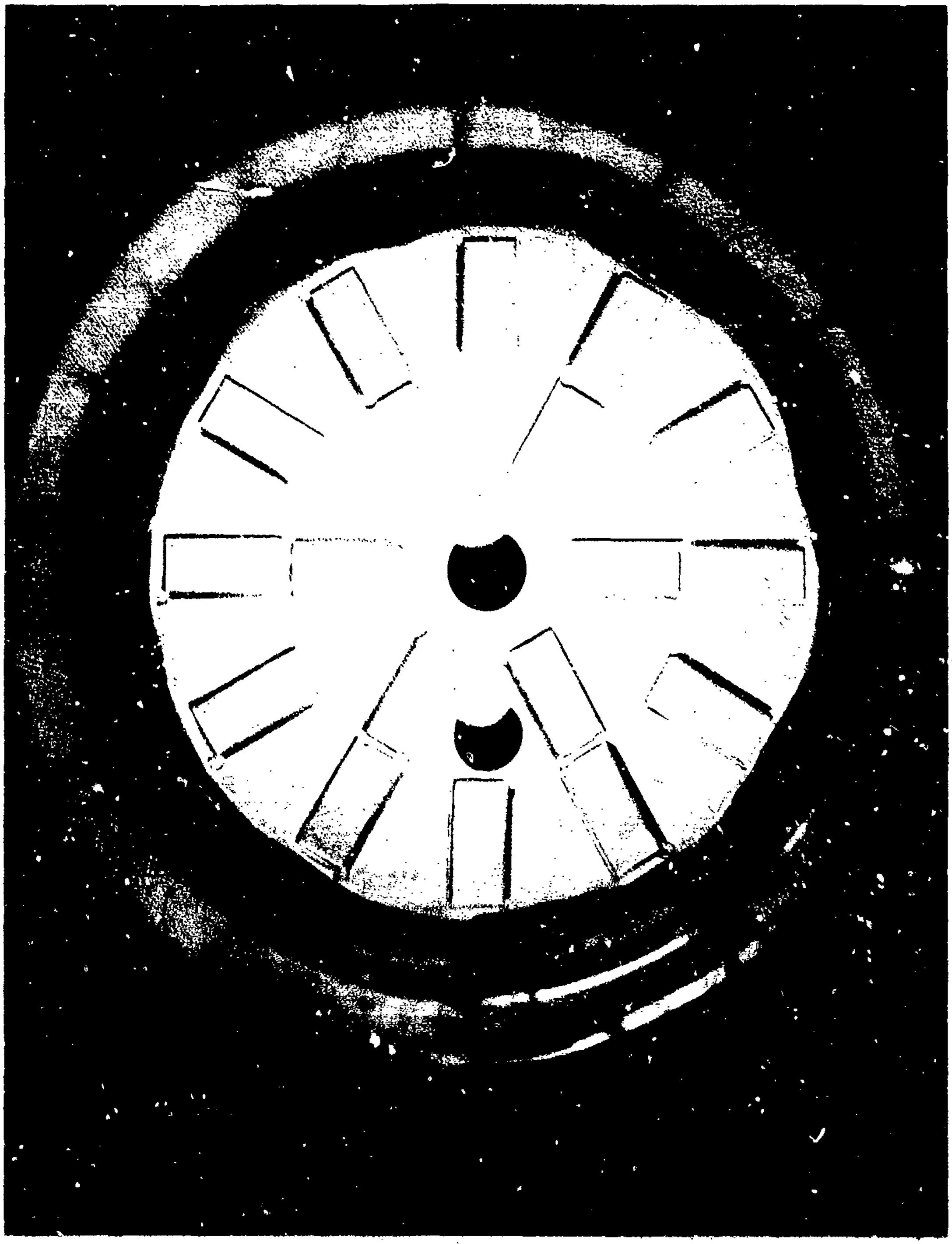


Figure 173. Preliminary Low-Emission, Extended-Length, Tangential-Swirl Liner Showing Internal Details.

TABLE LX. COMPARISON OF T63 NON-REGENERATIVE EMISSION /COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL COMBUSTOR, (2) EXTENDED-LENGTH COMBUSTOR, AND (3) EXTENDED LENGTH, TANGENTIAL-SWIRL COMBUSTOR.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended-Length, Tangential-Swirl Liner						
A. Emissions						
CO, (ppm)	[illegible]6.1	856.6	NO DATA TAKEN	NO DATA TAKEN	NO DATA TAKEN	NO DATA TAKEN
H/C, (ppm)	1380.0	1020.0				
NO_x, (On-Line, NDIR & NDUV) (ppm)	18.0	18.5				
NO_x, (Saltzman) (ppm)	9.13	10.4				
Smoke Number	73.14	74.66				
B. Pressure Loss (%)	5.63	5.40				
C. Temp. Profile (T_{max}/T_{Avg})	1.751	1.839				

Analysis of the test results for the "Extended-Length, Tangential-Swirl Liner" revealed the following:

- The predicted reduction in NO_x from the Task 2 studies were verified, as the NO_x emissions from the "Extended Length, Tangential-Swirl Liner" were the lowest of the three liners compared in Table LX.

- The interaction between the fuel spray from the pressure atomizing fuel injector and the upstream tangential swirl airflow was not conducive to a uniform flame pattern having high primary-zone recirculation. Evidence of this is the high T_{max}/T_{avg} exhaust temperature profile measured and the high levels of CO, C_xH_y, and smoke which resulted from insufficient high-temperature residence time (low recirculation).

- Test reports (previously available in the literature) on tangential-swirl combustion liners provided no data on the sizable increases in CO, C_xH_y, and smoke that would result from this type of combustor design.

The emission data in Table LX for cycle point 1 (idle) were converted to emission index for the LOH duty cycle. The computer results for this one data point are shown in Table XLVI.
A comparison was made of idle emission index values for the "Conventional Liner" and the "Extended-Length, Tangential-Swirl Liner." This comparison is presented in the emission index summary of Table XLVI. In this table the NO_x emission indexes were computed from the NDIR + NDUV instruments, which produced a different result than the Saltzman. For idle oxides of nitrogen, the NDIR + NDUV results showed an increase in NO_x of 6%. The Saltzman results showed a decrease of 51% at idle. Both measurement methods showed lower NO_x in comparing the "Extended-Length, Tangential-Swirl Liner" to the "Extended-Length Liner." The comparison of the other idle emissions for these two extended-length combustors showed significant increases in CO, C_xH_y, and smoke. These results can be seen in Table LX.

The tangential-swirl approach used in this combustion liner significantly increased the total emissions. This was possibly due to the deterioration of the primary-zone flow pattern created by the upstream component of the primary-zone swirl air. This upstream component's impinging on the fuel spray could have partially collapsed the fuel spray cone, thus overloading the primary-zone and disrupting the primary-zone recirculation. These conditions would reduce the primary-zone mixedness and residence time, resulting in low NO_x but high CO, C_xH_y, and smoke. Reversing the swirl louvers to produce a downstream axial swirl component or eliminating the induced axial component altogether would probably

increase the NO_x above the levels tested, but might significantly reduce the CO, C_xH_y, and smoke.

The tangential-swirl approach with an induced upstream axial component did not reduce the total emissions, and its inclusion in the final concept is not recommended.

SWIRL-DOME COMBUSTOR

One of the potential low-emission concepts selected in the Task 2 studies was the "Extended-Length, Radial-Swirl-Dome Combustor Liner." The concept is to replace the entire primary-zone air distribution system with an extended-length cylinder and a radial swirler dome through which all of the primary air is passed. Task 2 analytical studies indicated that emissions should decrease because:

- o The effect of the swirl is to improve the mixedness and reduce the local hot spot temperatures in the primary zone, thus reducing the concentrations of NO_x formed.
- o The primary-zone recirculation should be significantly improved.
- o The intermediate temperature zone upstream of the dilution holes is increased, thus increasing the residence time at these temperatures and resulting in reduced concentrations of carbon monoxide, hycrocarbons, and particulate carbon.

The "Extended-Length, Radial-Swirl-Dome Combustion Liner" was designed for the T63 nonregenerative combustor operating conditions tabulated in Table IV.

Two combustor configurations of this type were tested under this contract. The design details of each configuration are presented separately below.

Fixed-Geometry Wall Fuel-Film Injection - Design

A completely redesigned primary zone was fabricated to obtain the "Extended-Length, Radial-Swirl-Dome/Wall Fuel-Film Vaporizer Combustor Liner." The only parts of the conventional T63 liner retained in the design were the fuel injector bushing and the dilution zone section. The hole pattern in the dilution zone was modified as shown in the combustor comparison outlines in Figure 174. The "Radial-Swirl-Dome/Wall Fuel-Film Vaporizer Combustor Liner" has the following characteristics:

- o The total length is 14.35 inches compared to the 9.56-inch-length of the "Conventional T63 Liner."

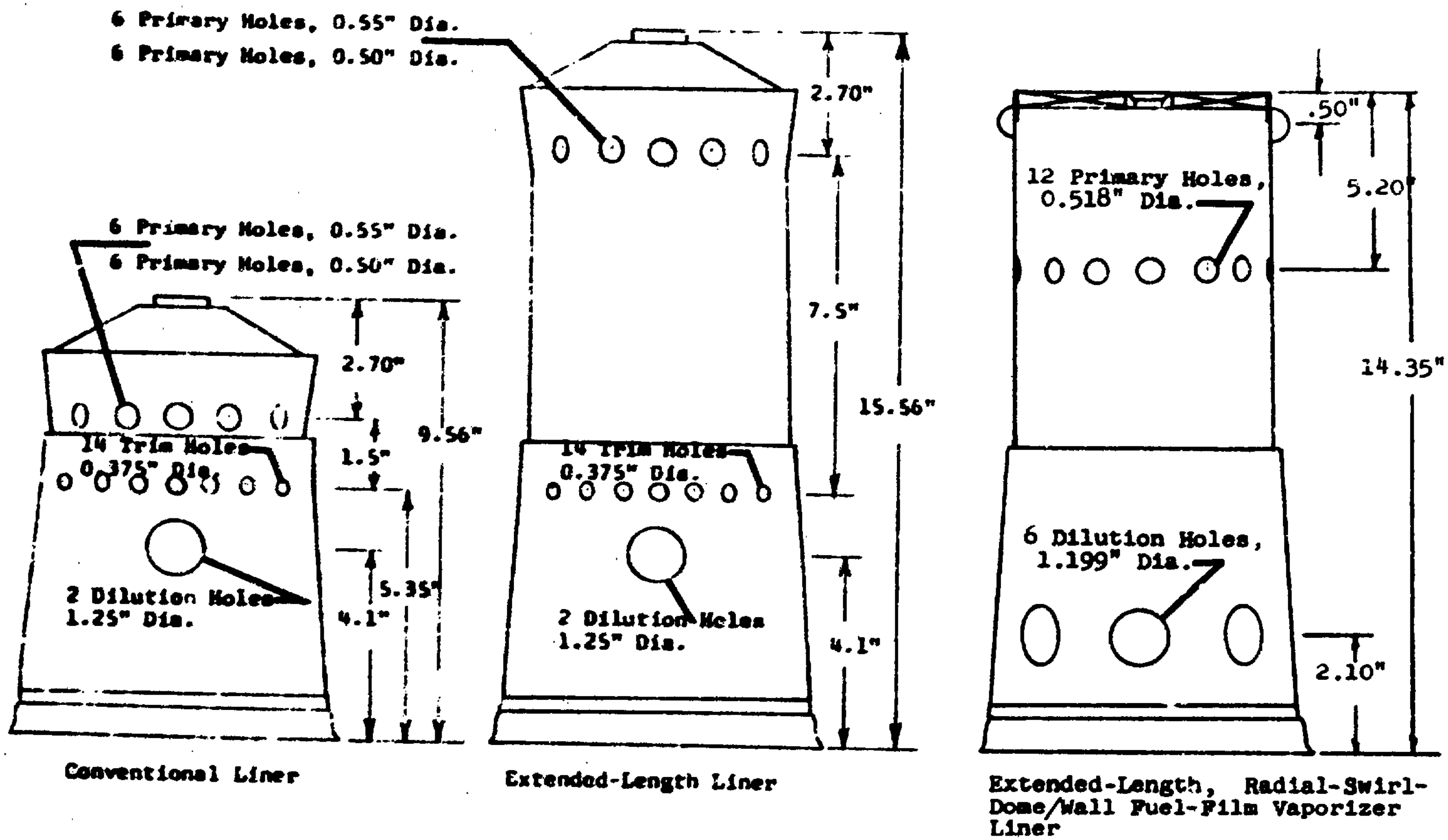


Figure 174. Hole Pattern and Size Comparison of Liners.

- The fuel was added to the combustor through a wall fuel-film injection system which injected twelve streams of fuel tangentially on the liner inner wall in the direction of the swirling primary-zone air. The injection ports were located 0.50 inch downstream of the liner dome.

- The through-put equivalence ratio downstream of the fuel injection ports was 3.9 when all of the fuel was vaporized.

- The through-put equivalence ratio downstream of the row of primary holes was 0.98 at 100% power fuel/air ratio. This compares to an equivalence ratio of 0.77 for the conventional T63 liner.

- Swirl vanes, shown in Figure 174, were installed in the dome to provide a high shear velocity across the fuel film for rapid vaporization and to establish intense primary-zone recirculation for uniform combustion.

- The primary zone is cooled by the high-velocity air-fuel mixture created by the dome swirl vanes.

- The conventional liner trim and dilution holes were closed, and a single row of dilution holes was added 2.10 inches upstream of the combustor exit. This design change was made to delay the quench of CO, C_xH_y, and C reactions.

Variable-Geometry, Conventional Atomizer - Design

For this configuration, the primary zone was also completely redesigned to obtain the "Extended-Length, Radial-Swirl-Dome/Variable-Dilution Geometry/Standard Fuel Injection Combustor Liner." The only parts of the conventional T63 liner retained in this design were the fuel injector, the fuel injector bushing, and the dilution zone section. This combustor has the following characteristics:

- The total length is 14.35 inches, the same as the "Wall Fuel-Film Vaporizer" configuration.

- The fuel injector was the standard T63 dual-orifice pressure atomizer.

- The "Variable-Geometry" dilution section produced primary-zone equivalence ratios, based on through-put swirler air, both higher and lower than the 0.77 conventional T63 liner primary-zone equivalence ratio.

- All of the primary air entered through the dome swirler. (Later cold-flow tests revealed that a significant portion of the dilution air was drawn upstream into the primary zone.)

- A 3.0-inch diameter orifice flame holder was installed 2.0 inches downstream of the swirler.

- Swirl vanes, shown in Figure 175, were installed in the dome to establish intense primary-zone recirculation for uniform combustion.

- The primary zone was cooled by the high-velocity air entering the primary zone through the swirl vanes.

- The conventional liner trim holes were closed, and a six-hole-pattern row of dilution holes was added in the same axial location as the two conventional liner dilution holes. Over these circular holes was a slip band having square holes, which provided the variable geometry for the dilution zone. The purpose of the variable geometry was to control the primary-zone equivalence ratio and thus the combustion temperature to reduce the formation of the NO_x and to consume the CO, C_xH_y, and carbon.

- The additional length of this combustor was to allow for more complete oxidation of the CO, C_xH_y, and C reactions.

The "Extended-Length, Radial-Swirl-Dome Combustor Liner" was tested at the conditions given in Table IV. The tests were conducted at steady-state conditions in the DDA Combustion Research Laboratory, using JP-4 fuel. The experimental results for each combustor configuration utilizing a radial swirl dome are presented below.

Fixed-Geometry Wall Fuel Film Injection - Experimental Results

The experimental CO and C_xH_y emission results presented in Figures 176 and 177 show significant reductions in emissions when compared to the "Conventional T63-A-5A Liner" emissions. Compared to the same length combustor, "Extended-Length Liner," the CO was slightly lower at low power conditions and slightly higher at high power conditions. Except for the idle point, the H/C emissions compared in a similar manner for the same length liners. The NO_x results, presented in Figure 178, show higher NO_x emissions than the "Conventional T63-A-5A" combustor. The data exhibit the same characteristics (the curves nearly parallel each other), but there is approximately 7 ppm higher concentration at all operating points. Compared to the "Extended-Length Liner", the NO_x emissions were slightly higher at low power conditions, somewhat lower at the higher power conditions, and considerably lower at maximum power. The smoke was decidedly higher than both the "Conventional T63-A-5A Combustor Liner" and the "Extended-

Figure 175. Preliminary Low-Emission, Extended-Length, Radial-Swirl-Dome Combustor Liner - Variable Geometry With Conventional Pressure Atomizer Fuel Injection.

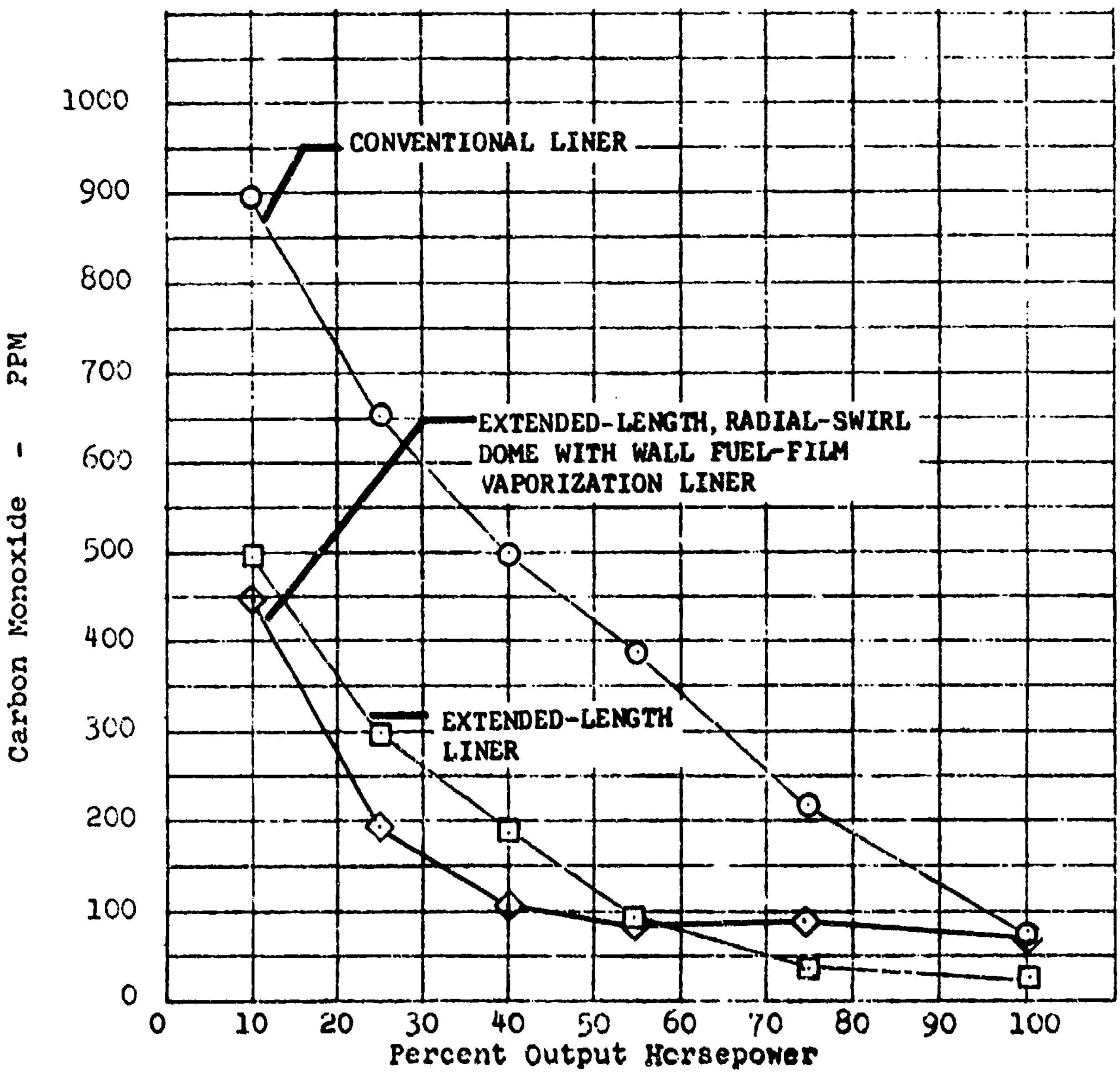


Figure 176. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Radial-Swirl-Dome With Wall Film Vaporization and T63 Baseline Combustors.

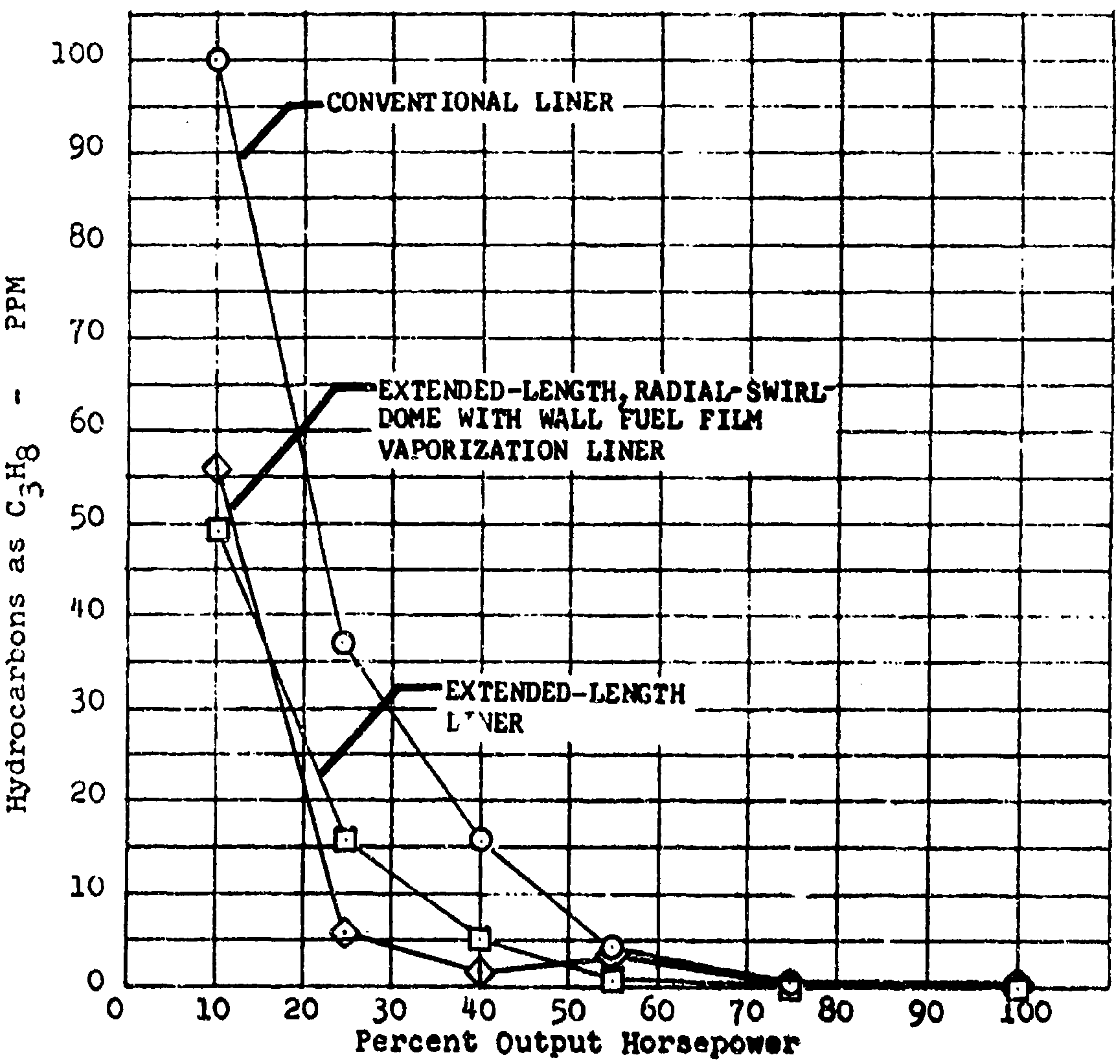


Figure 177. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Radial-Swirl-Dome With Wall Film Vaporization and T63 Baseline Combustor.

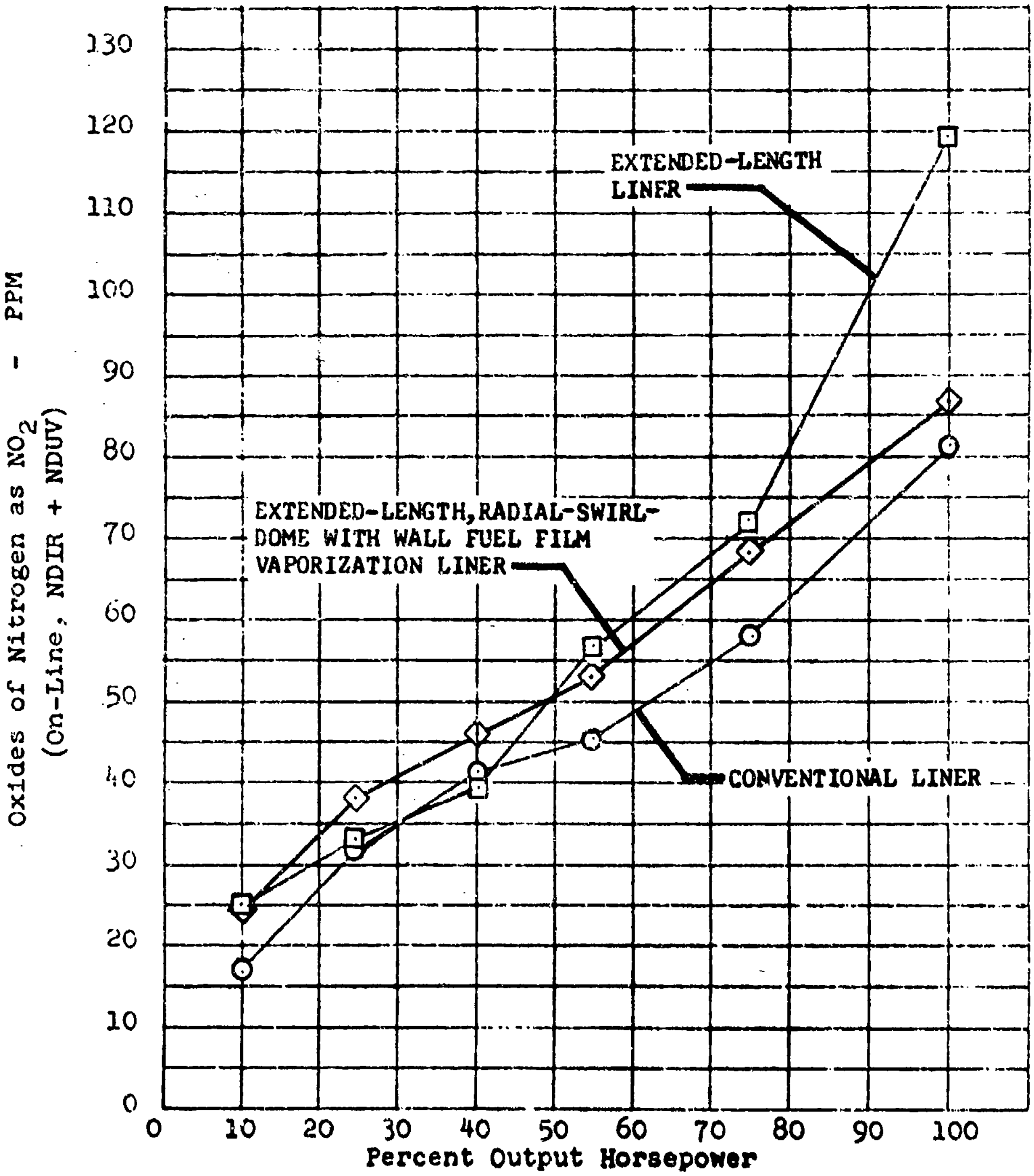


Figure 178. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Radial-Swirl-Dome With Wall Film Vaporization and T63 Baseline Combustors.

Length Liner," as shown by the data in Figure 179. The temperature profile (T_{max}/T_{avg}) from the "Extended-Length, Radial-Swirl-Dome Combustor Liner, Fixed Geometry, Wall Fuel Film Injection Configuration" was considerably worse than from the Conventional T63-A-5A Liner" and, for most of the operating conditions, also worse than from the "Extended-Length Liner. These data are presented in Figure 180. With development, the temperature profile could be improved to an acceptable level.

The measured pressure loss of the "Wall Fuel Film Injection Liner" was nominally 5.9%. As seen from Table LXI, this pressure drop compares with 4.4% for the "Conventional Liner" and 4.8% for the "Extended-Length Liner."

Using the emissions data presented in Table LXI and Figures 176 through 179, the emission index for the selected LOH duty cycle was calculated. The total emission index for the "Wall Fuel Film Injection Liner" was 15.426 lb emissions/1000 lb fuel, as shown in Figure 181. This compares to 32.945 lb/1000 lb fuel for the "Conventional Liner" as shown in Figure 181. Therefore, the total emissions from the "Wall Fuel Film Injection Liner" were 47% of the total emissions from the "Conventional Liner" and thus met the 50% reduction of total emissions part of the contract objectives. However, as shown in Table XLVI, the NO_x and particulates emission index values increased above the constituent levels of the "Conventional Liner" and therefore did not meet the contract objective of no constituent emission increase. For the same length liner ("Extended Length"), the "Wall Fuel Film Injection Liner" had approximately the same total emissions, but there was a major increase in smoke/particulates.

Visual examination of the "Wall Fuel Film Injection Liner" after testing showed some thermal distortion of the swirler blades, which explains the decreasing values of pressure drop with time (increasing power level operating conditions). The swirl vanes were constrained by the cold fuel manifold. Hot combustion products traveling upstream in the swirl vortex accounted for the heating of the swirl vanes. The resulting compressive stress forced the vanes to spread apart. There was no other apparent damage to the combustor.

Variable Geometry, Conventional Atomizer - Experimental Results

The emissions for this configuration for various geometry settings are summarized in Table LXII. The test procedure for this variable-geometry combustor was to adjust the geometry at each cycle point to only those settings which produced constituent emission concentrations within levels of interest. The emissions data are compared with baseline combustor liner emissions in Figures 182 through 185. It was possible with various geometry

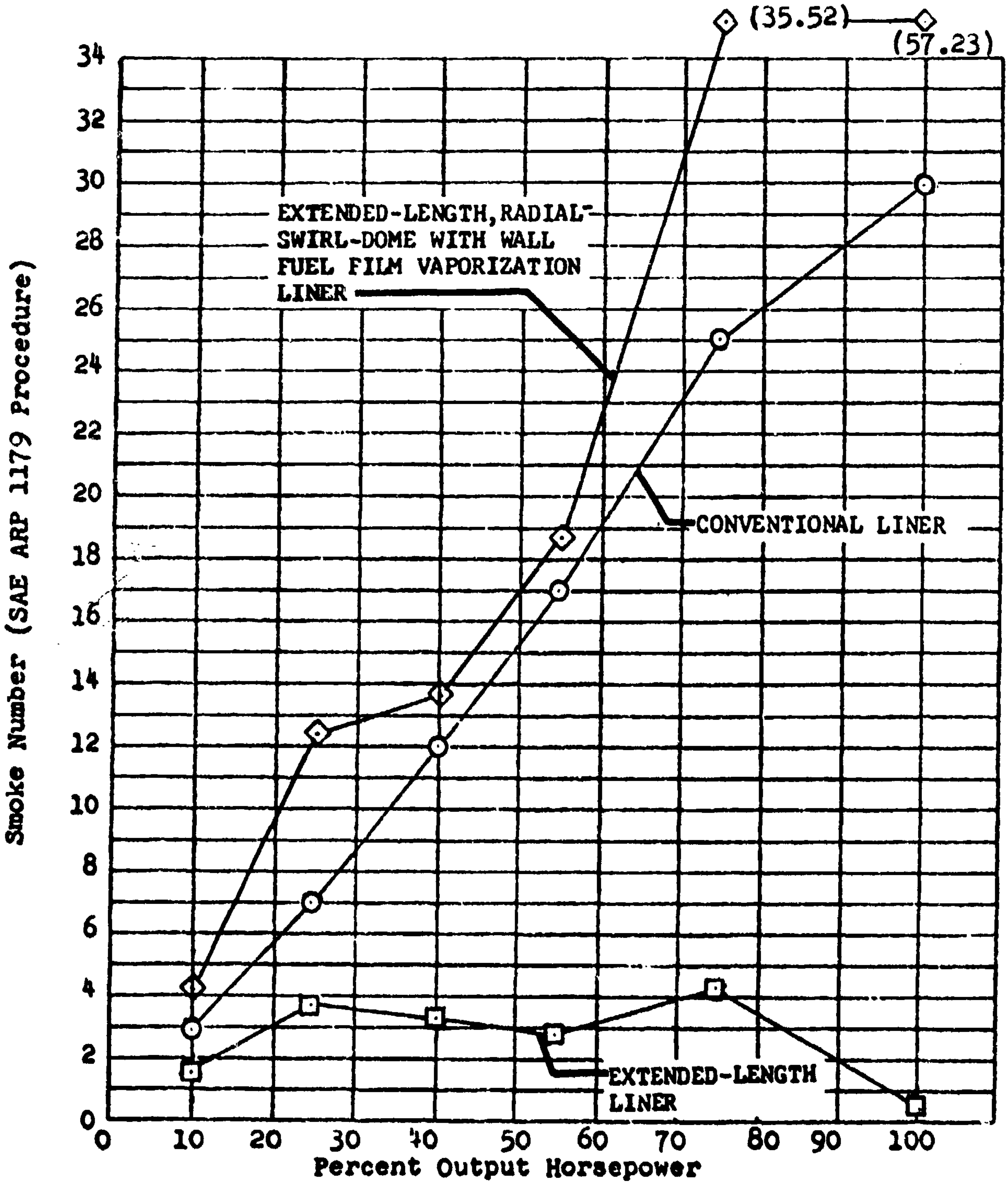


Figure 179. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Radial-Swirl-Dome With Wall Film Vaporization and T63 Baseline Combustors.

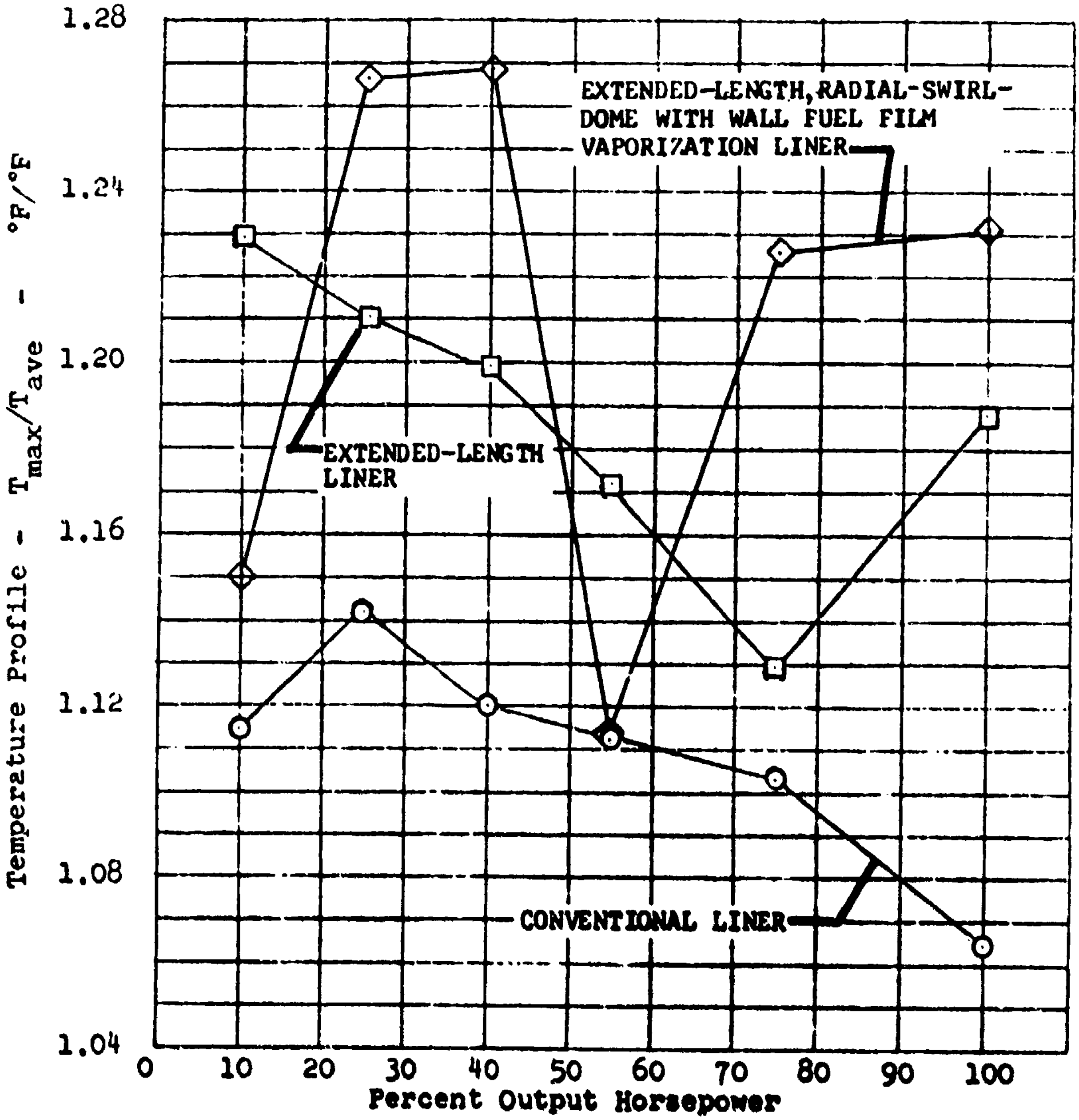


Figure 180. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Radial-Swirl-Dome With Wall Film Vaporization and T63 Baseline Combustors.

TABLE LXI. COMPARISON OF T63 NONREGENERATIVE EMISSION COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, (3) EXTENDED-LENGTH, RADIAL SWIRL-DOME LINER WITH WALL FUEL FILM VAPORIZER

	Cycle Point					
	[illegible]	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.62	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.069
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.9	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Radial-Swirl-Dome-Extended-Length Liner With Wall Fuel Film Vaporizer						
A. Emissions						
CO, (ppm)	445.9	191.9	108.6	82.8	90.7	71.5
H/C, (ppm)	56.0	5.8	1.9	2.9	.7	.5
NO_x, (On-Line, NDIR & NDUV) (ppm)	24.5	38.0	46.0	53.0	68.5	86.5
NO_x, (Saltzman) (ppm)	28.2	42.0	53.6	66.6	88.7	110.0
Smoke Number						
B. Pressure Loss (%)	6.36	6.26	6.22	5.94	5.66	5.22
C. Temp. Profile (T_{max}/T_{Avg})	1.150	1.267	1.269	1.113	1.226	1.231

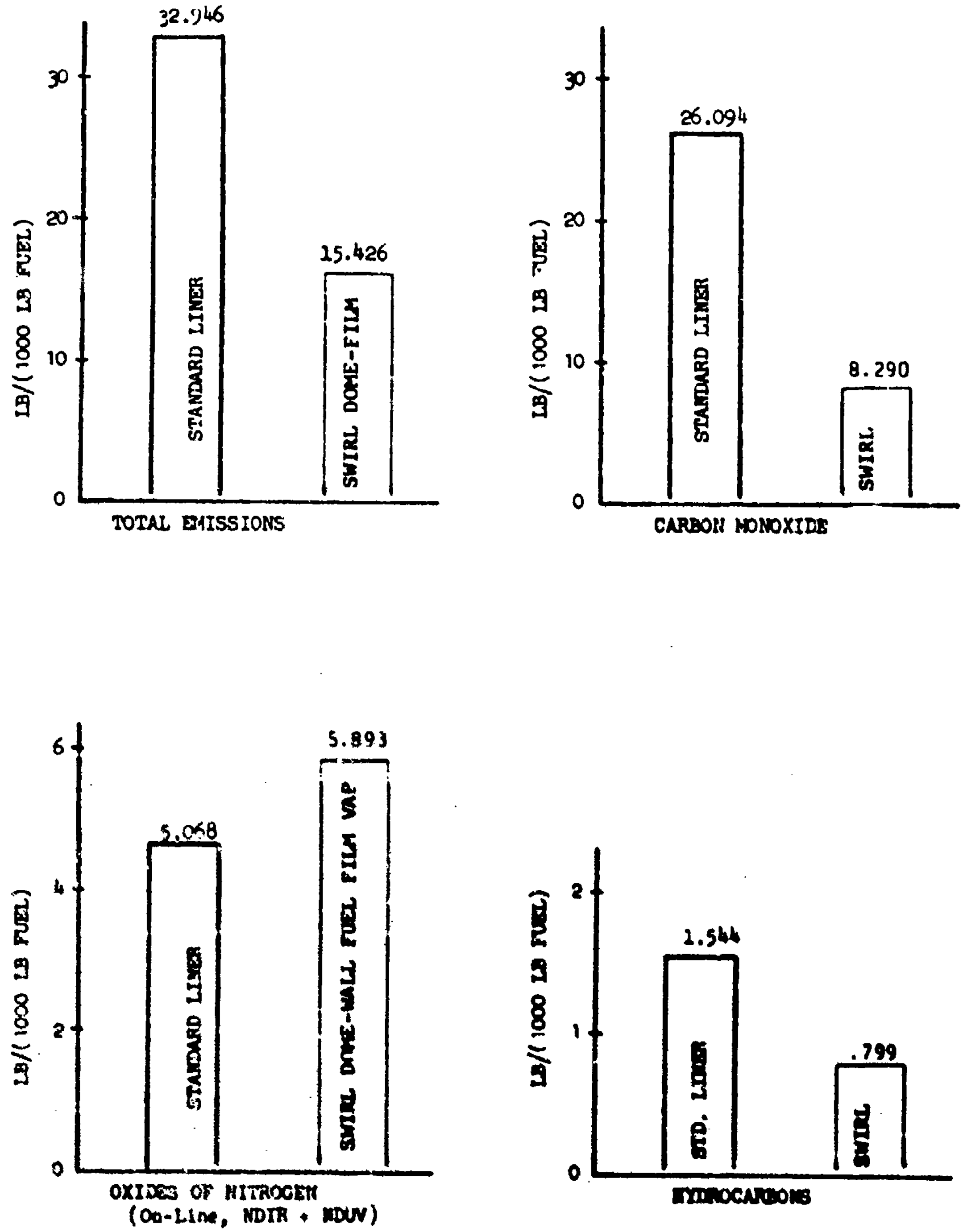


Figure 181. Nonregenerative T63-A-5A Emission Index Comparison Extended-Length, Radial-Swirl-Dome-Wall Fuel Film Vaporizer.

TABLE LXII. EMISSION DATA FOR EXTENDED-LENGTH, RADIAL-SWIRL-DOME LINER WITH VARIABLE-GEOMETRY AT NONREGENERATIVE CONDITIONS

Dilution Zone Variable	Cycle Point					
	1	6	5	4	3	2
Geometry Setting						
100% Open						
CO (ppm)	166.8					
H/C (ppm)	1.6					
NO_x (NDIR & NDUV) (ppm)	42.0					
NO_x (Saltzman) (ppm)	45.4					
Smoke Index	2.42					
80% Open						
CO (ppm)	170.9	1[illegible].0				
H/C (ppm)	2.4	0.9				
NO_x (NDIR & NDUV) (ppm)	30.5	[illegible].5				
NO_x (Saltzman)	4[illegible]	58.4				
Smoke Index	2.10	0.28				
60% Open						
CO (ppm)	202.9	121.8	123.7	141.0		
H/C (ppm)	6.5	1.5	1.3	.4		
NO_x (NDIR & NDUV) (ppm)	32.0	53.5	66.0	72.5		
NO_x (Saltzman) (ppm)	39.3	59.8	77.5	81.4		
Smoke Index	2.25	0.28	2.28	2.77		
40% Open						
CO (ppm)	400.[illegible]	179.2	112.4	101.2		
H/C (ppm)	36.0	5.0	[illegible].8	.5		
NO_x (NDIR & NDUV) (ppm)	20.5	43.0	66.0	77.5		
NO_x (Saltzman) (ppm)	27.7	47.7	73.2	91.2		
Smoke Index	4.74	1.68	1.59	1.71		
20% Open						
CO (ppm)		619.2	362.5	183.4		
H/C (ppm)		48.0	15.4	2.4		
NO_x (NDIR & NDUV) (ppm)		26.5	36.5	53.5		
NO_x (Saltzman) (ppm)		29.4	40.5	64.7		
Smoke Index		5.47	3.44	2.47		
10% Open						
CO (ppm)			1120.8			
H/C (ppm)			110.0			
NO_x (NDIR & NDUV) (ppm)			33.0			
NO_x (Saltzman) (ppm)			30.8			
Smoke Index			5.24			
0% Open						
CO (ppm)				465.2	1004.2	
H/C (ppm)				.5	99.0	
NO_x (NDIR & NDUV) (ppm)				38.0	67.0	
NO_x (Saltzman) (ppm)				48.8	70.0	
Smoke Index				41.75	3.22	

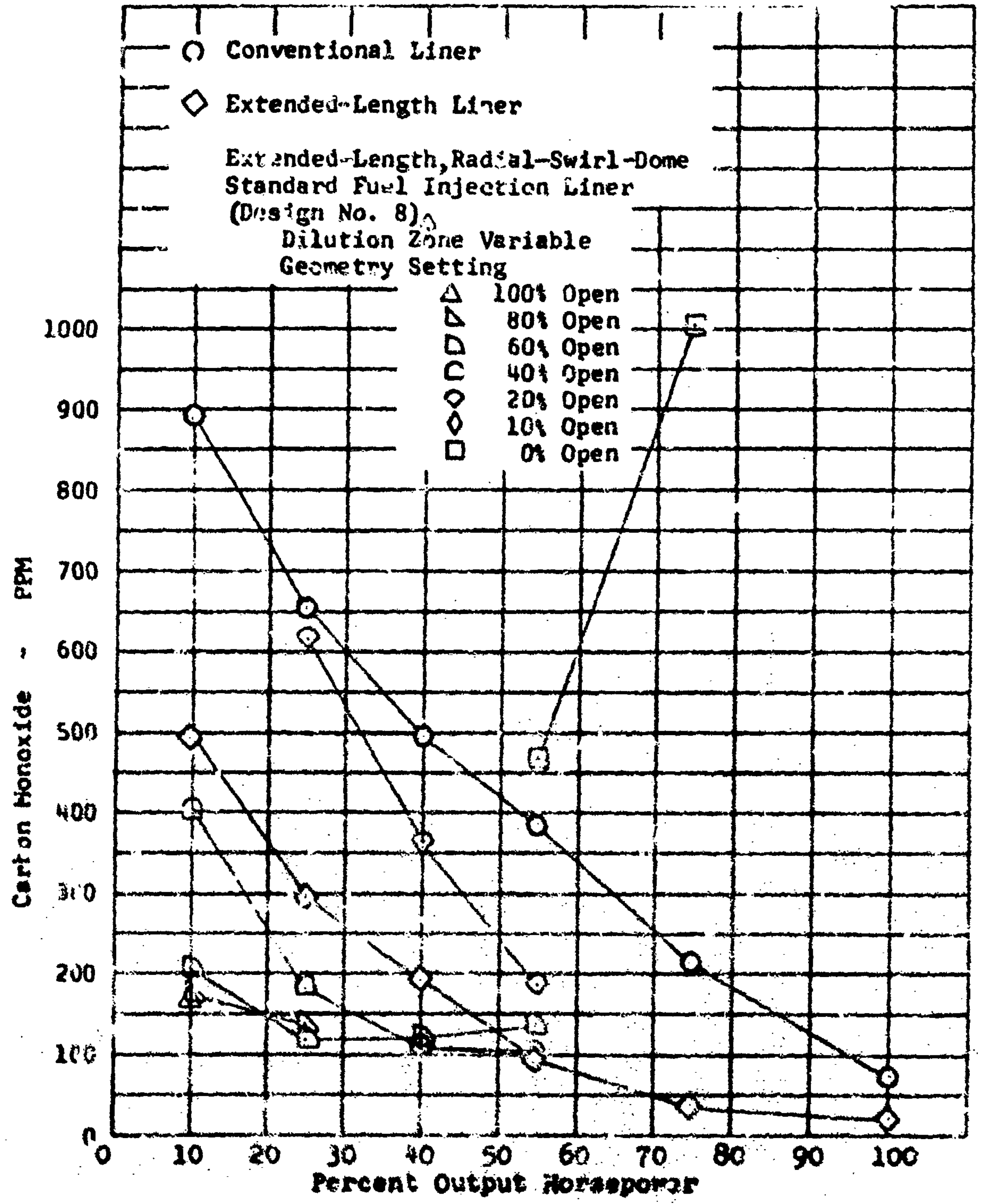


Figure 182. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Radial-Swirl-Dome Standard Fuel Injection Combustor and T63 Baseline Combustors.

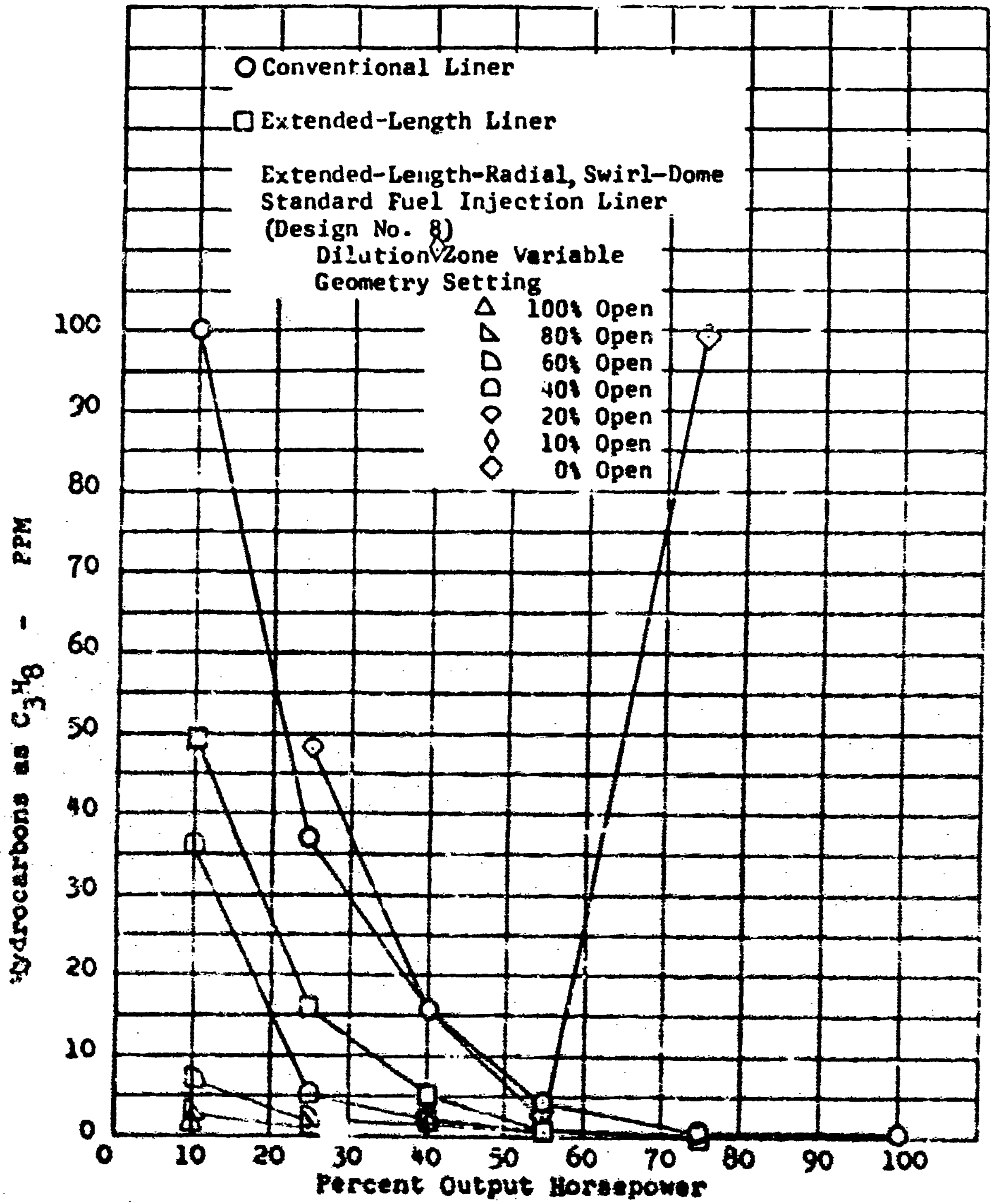


Figure 183. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Radial-Swirl-Dome Standard Fuel Injection Combustor and T63 Baseline Combustors.

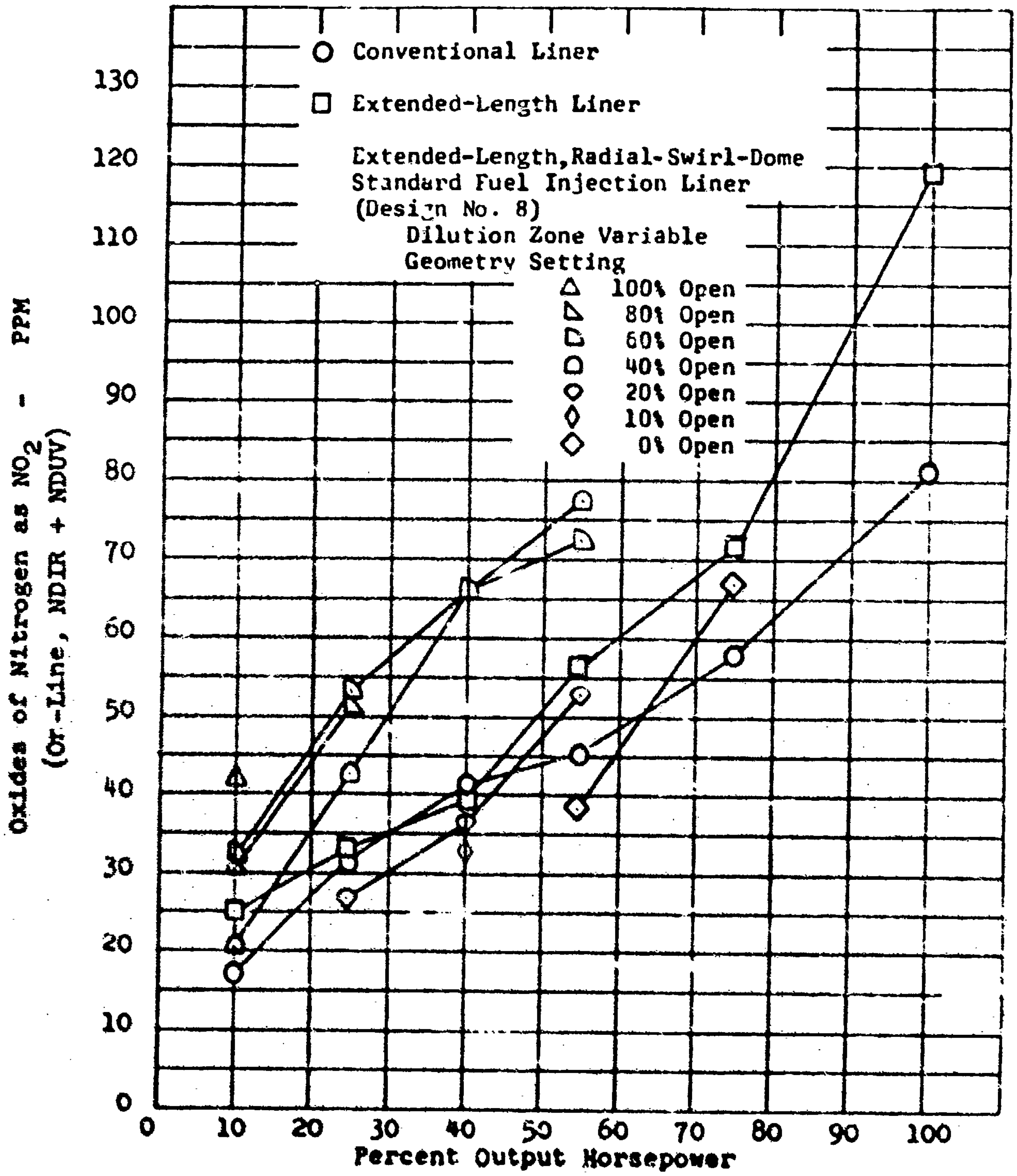


Figure 184. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Radial-Swirl-Dome Standard Fuel Injection Combustor and T63 Baseline Combustors.

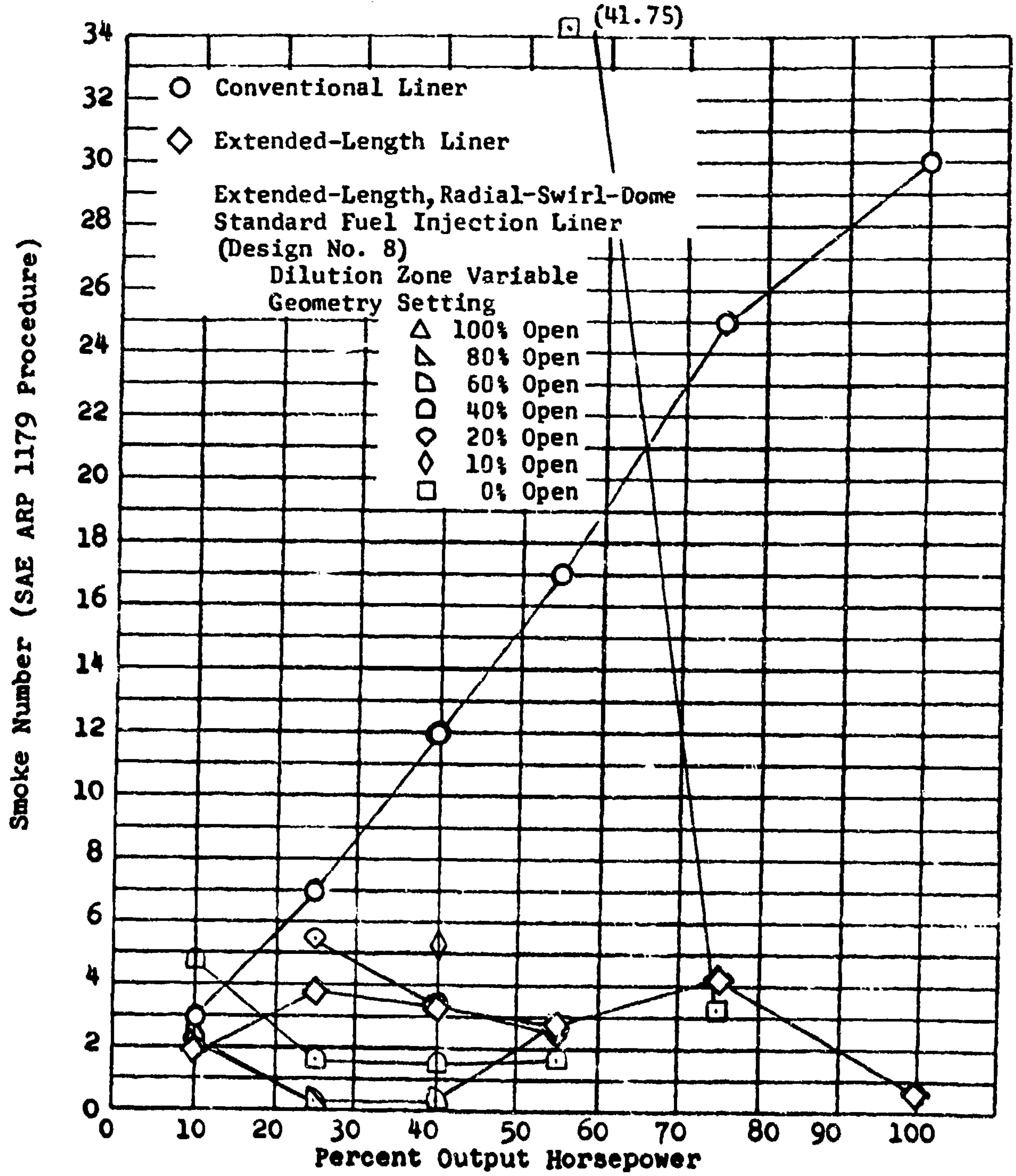


Figure 185. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Radial-Swirl-Dome Standard Fuel Injection Combustor and T63 Baseline Combustors.

settings to trade reductions in CO and C_xH_y concentrations for increases in NO_x at the lower power conditions, but at the higher power conditions the combustor was unable to trade increases in CO and C_xH_y for reductions in NO_x. At the 75% power condition, the fully closed geometry setting (0% open) showed that the combustor could not reduce the NO_x concentrations below the "Conventional T63-A-5A Liner" NO_x levels, see Figure 184. The accompanying CO and C_xH_y concentrations, Figures 182 and 183, were many times higher than those of the "Conventional T63-A-5A Liner." Smoke from the variable-geometry configuration, Figure 185 was quite low except for the fully closed position at 55% power. The combustor exhaust temperature profile, Table LXIII and Figure 186, improved as the dilution holes were closed until the 20% open position was reached. The 10% and 0% open positions showed significant deterioration of the temperature profile. The temperature profile degradation was probably caused by the failure of the flameholder. Consequently, (1) because the NO_x concentrations could not be reduced below baseline levels at 75% power and (2) because of the worsening trend of the temperature profile at 75% power, there was no data taken at 100% power.

Liner pressure drop, Table LXIV, varied from 6.2% at 100% open to 22.8% at 0% open. These values are considerably higher than the "Conventional Liner" and the "Extended-Length Liner" pressure drops.

Using the emission data presented in Table LXII and Figures 182 through 185, the emission index values for each combustor operating point and geometry setting were computed. A total LOH duty cycle emission index value was not computed since no data was taken at Cycle Point 2 - 100% power. The minimum emission index for Cycle Points 1, 3, 4, and 5 was 29.50 lb total emissions/1000 lb fuel based on fuel usage from all five cycle points, i.e., zero emissions at maximum power, Cycle Point 2. This minimum emission resulted from the following geometry settings:

Cycle Point	% Power	% Open Geometry Setting
1	10	80
5	40	40
4	55	40
3	75	0

The constituent emission index values, based on 140.05 lb fuel used, were the following:

TABLE LXIII. COMPARISON OF EXHAUST TEMPERATURE PROFILE (T_{max}/T_{avg}) FOR EXTENDED-LENGTH, RADIAL-SWIRL-DOME LINER HAVING VARIABLE-GEOMETRY, WITH BASELINE COMBUSTOR LINERS AT NONREGENERATIVE CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended-Length, Radial-Swirl-Dome Liner, Design #8, Having Variable Geometry at						
100% Open	1.264					
80% Open	1.221	1.221				
60% Open	1.202	1.174	1.142	1.152		
40% Open	1.181	1.188	1.124	1.105		
20% Open		1.109	1.079	1.078		
10% Open			1.095			
0% Open				1.129	1.294	

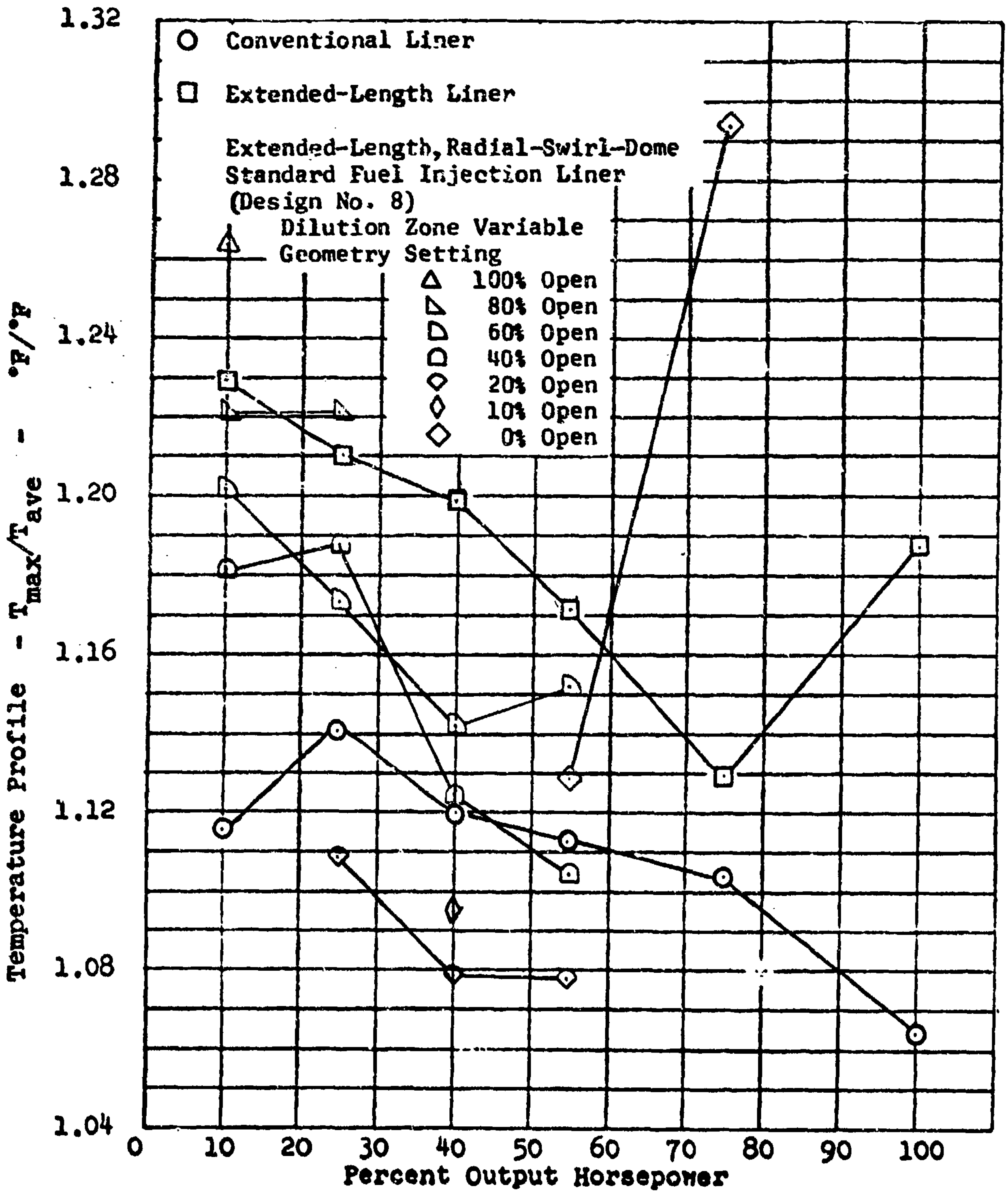


Figure 186. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Radial-Swirl-Dome Standard Fuel Injection Combustor and T63 Baseline Combustors.

TABLE LXIV. COMPARISON OF PRESSURE LOSS (%) FOR EXTENDED-LENGTH, RADIAL SWIRL DOME LINER HAVING VARIABLE GEOMETRY WITH BASELINE COMBUSTOR LINERS AT NONREGENERATIVE CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner	4.63	4.51	4.53	4.44	4.38	4.14
II. Extended-Length Liner	5.10	4.61	5.09	4.91	4.74	4.59
III. Extended-Length, Radial-Swirl-Dome Liner, Design #8 Having Variable Geometry at						
100% Open	6.18					
80% Open	6.47	6.72				
60% Open	7.17	7.33	7.21	6.83		
40% Open	9.02	9.14	9.04	8.75		
20% Open		13.30	13.59	12.57		
10% Open			18.91			
0% Open				22.77	22.92	

Constituent	Emission Index lb Emissions/1000 lb Fuel	Emission Index Percent of "Conventional Liner"
Hydrocarbon	2.38	154%
Carbon Monoxide	20.19	77%
Oxides of Nitrogen	6.90	136%
Smoke/Particulates	.03	1%
Total	29.50	90%

It must be remembered that the above emission index values are based only on Cycle Points 1, 3, 4, and 5. However, the percentages in the table were computed using the four emission points for the "Swirl Dome Liner" and all five emission points for the "Conventional T63-A-5A Liner." Thus, if data were obtained for Cycle Point 2 (100% power), the emissions would all be somewhat higher than the values presented.

Visual examination of the combustor liner after testing revealed that two of the four welds supporting the flameholder had broken, thus allowing the flameholder to distort. This failure may have accounted for the high levels of CO and C_xH_y at 55% and 75% power settings.

The "Extended-Length, Radial-Swirl-Dome Combustor Liner" with Wall Fuel Film Injection and Fixed Combustor Geometry produced 53% lower total emissions than the "Conventional T63-A-5A Liner." This reduction satisfied the "50% minimum reduction in total emissions" portion of the contract requirements, but the requirement of "no increase in any constituent emission" was not met by either NO_x (16% increase) or smoke/particulates (85% increase above baseline).

Variable geometry in the "Extended-Length, Radial-Swirl-Dome Combustor Liner" with Conventional Pressure Atomizing Injection did not provide sufficient control of the primary zone to maintain low emissions. This lack of variable geometry control was probably due to the failure of the flameholder at the higher power operating conditions. A more substantially held flameholder should provide improved emission control.

Additional emission reductions might be achieved by further "tailoring" of the swirl-intensity, flow splits between primary and dilution zones and the design of a flameholder to stabilize the reaction zone.

Comparing the "Extended-Length, Radial-Swirl-Dome Combustor Liner" concept with other combustor configurations tested on this contract, it was recommended that no additional effort be expended on this type of combustor at this time.

RICH PREMIX/SWIRL COMBUSTOR

One of the potential concepts selected from the Task 2 studies and partial results from Task 3 was the "Extended Length-Premix Cup/Liquid Fuel/Swirl Dome Combustor Liner." The concept was to incorporate the following features to reduce the emissions:

- A premix cup (prechamber) to mix the fuel and air and to partially vaporize and react the fuel. This would improve the flame homogeneity, reduce hotspots, and therefore reduce the emissions.

- Fuel-rich mixtures (ϕ = 2.0 at max. power) in the premix cup. This would reduce NO_x from the precombustion and early phases of the primary combustion process.

  (Note: This will work only if sudden quench is achieved from the fuel rich to the lean overall fuel/air ratio condition).

- Delayed dilution to allow maximum time at intermediate temperature to consume the CO, H/C, and particulate emissions. The intermediate temperature must be low enough to avoid NO_x formation.

- Convection cooling in the primary zone instead of film cooling to avoid quenching of the CO, H/C, and C reactions in the relatively cold film air.

- Extended length to allow additional residence time to react the CO, H/C, and particulates. Previous experiments in Task 2 had shown that the extended length would significantly reduce CO and H/C emissions with a small increase in NO_x emissions.

The "Extended-Length, Premix-Cup/Liquid Fuel/Swirl-Dome Combustor Liner" was designed for the T63 nonregenerative combustor operating conditions tabulated in Table IV.

A completely redesigned primary zone was fabricated to obtain the "Extended-Length, Premix-Cup/Liquid Fuel/Swirl-Dome Combustor Liner." The only part of the conventional T63 liner retained in the design was the dilution zone section, and its hole pattern was modified as shown in Figure 187. The "Extended-Length, Premix-Cup/Liquid Fuel/

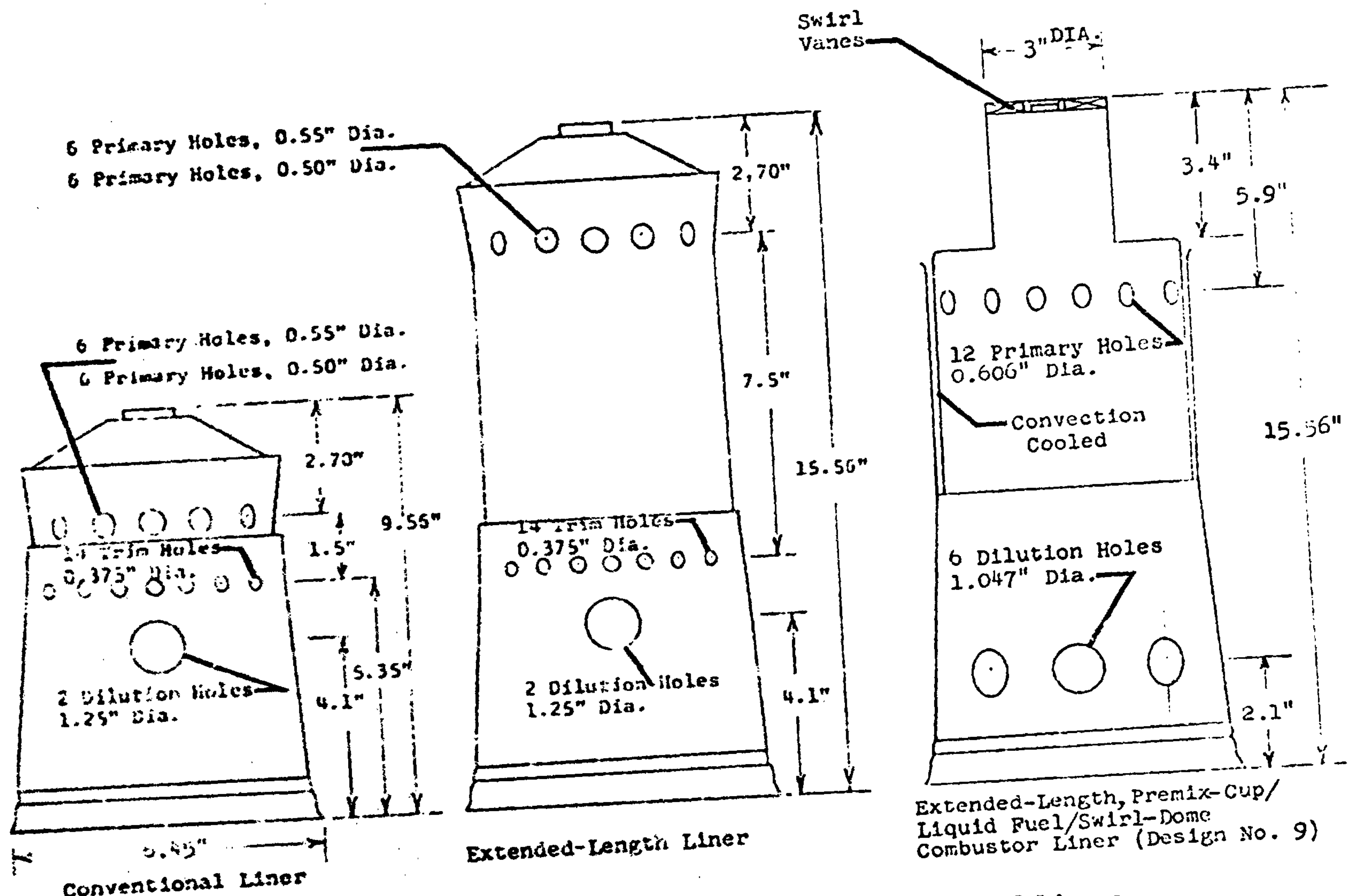


Figure 187. Hole Pattern and Size Comparison of Liners.

Swirl-Dome Combustor Liner" as shown in Figure 188 has the following characteristics:

- The total length is 15.56 inches compared to a 9.56-inch for the "Conventional T63" liner.
- The fuel injector was the standard T63 dual-orifice pressure atomizer.
- The fuel-air premix chamber was 3 inches in diameter by 3.40 inches in length.
- Swirl vanes, as shown in Figures 187 and 188, were installed in the dome of the premix chamber to recirculate some of the combustion products back into the premix chamber. This provides partial fuel vaporization and ignition in the premix chamber.
- The primary zone was convection cooled as shown in Figure 188 instead of the conventional film cooling.
- The airflow distribution for the "Extended-Length, Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" was designed for 2.0 equivalence ratio in the premix cup and 0.5 equivalence ratio just downstream of the primary holes. These equivalence ratio values are for T63 nonregenerative maximum-power conditions. The conventional T63 non-regenerative combustor operates at 0.77 equivalence ratio in the primary zone.
- The conventional liner trim and dilution holes were combined into a single row of holes with an increased area from 4 in.^{2} to 5.2 in.^{2}. As shown in Figure 187, this single row of dilution holes was moved aft to 2.1 inches from the exit. This design change was made to delay the quench of CO, H/C, and C reactions.

The "Extended-Length, Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" was tested at the conditions tabulated in Table IV. In addition to the Table IV test conditions, the combustor was tested at three additional fuel/air ratios at the idle (10% power) conditions. The tests were conducted at steady-state conditions, in the DDA Combustion Research Laboratory, using JP-4 fuel.

The CO and H/C emission results, plotted in Figures 189 and 190 respectively, show significant reductions in emissions compared to either the "Conventional T63-A-5A Liner" or the "Extended-Length Liner." The NO_x results, presented in Figure 191, show general emission improvement at the lower power conditions but higher NO_x at the high power conditions. The smoke trends, as shown in Figure 192, are also somewhat similar to the "cross-over" encountered in the NO_x data.

Figure 188. Preliminary Low-Emission, Extended-Length, Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner

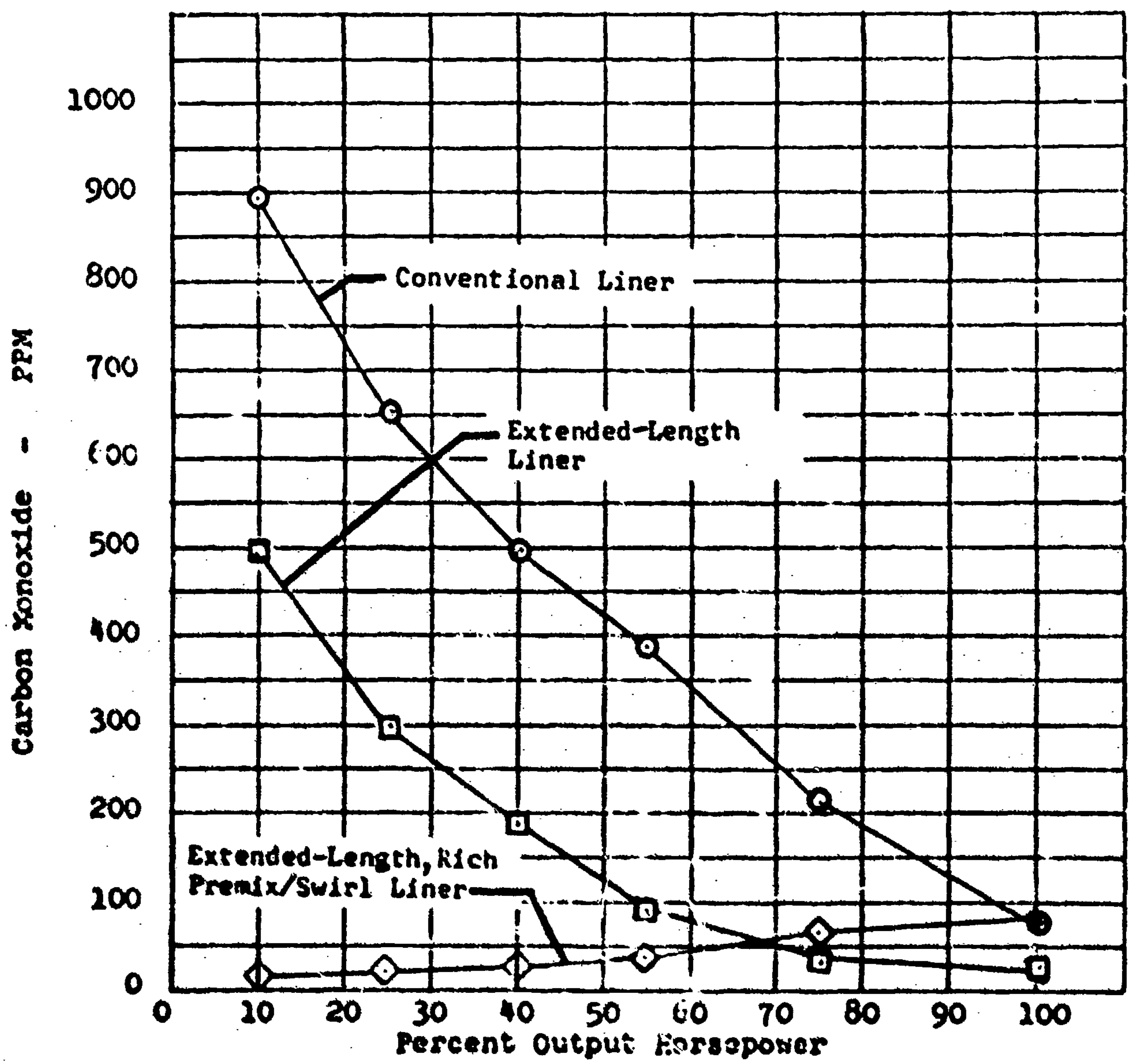


Figure 189. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Rich Premix/Swirl Combustor and T63 Baseline Combustors.

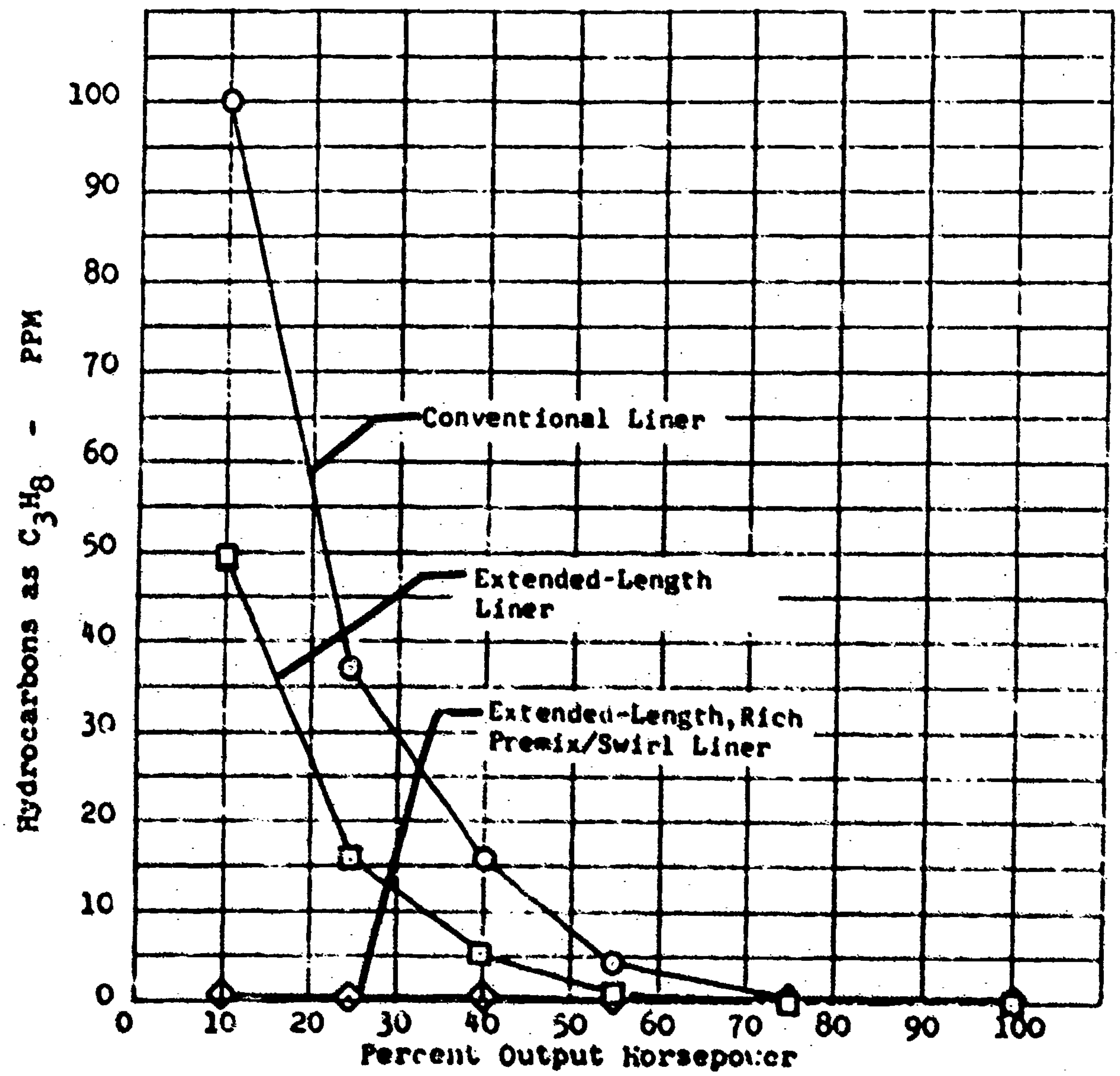


Figure 190. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Rich Premix/Swirl Combustor and T63 Baseline Combustors.

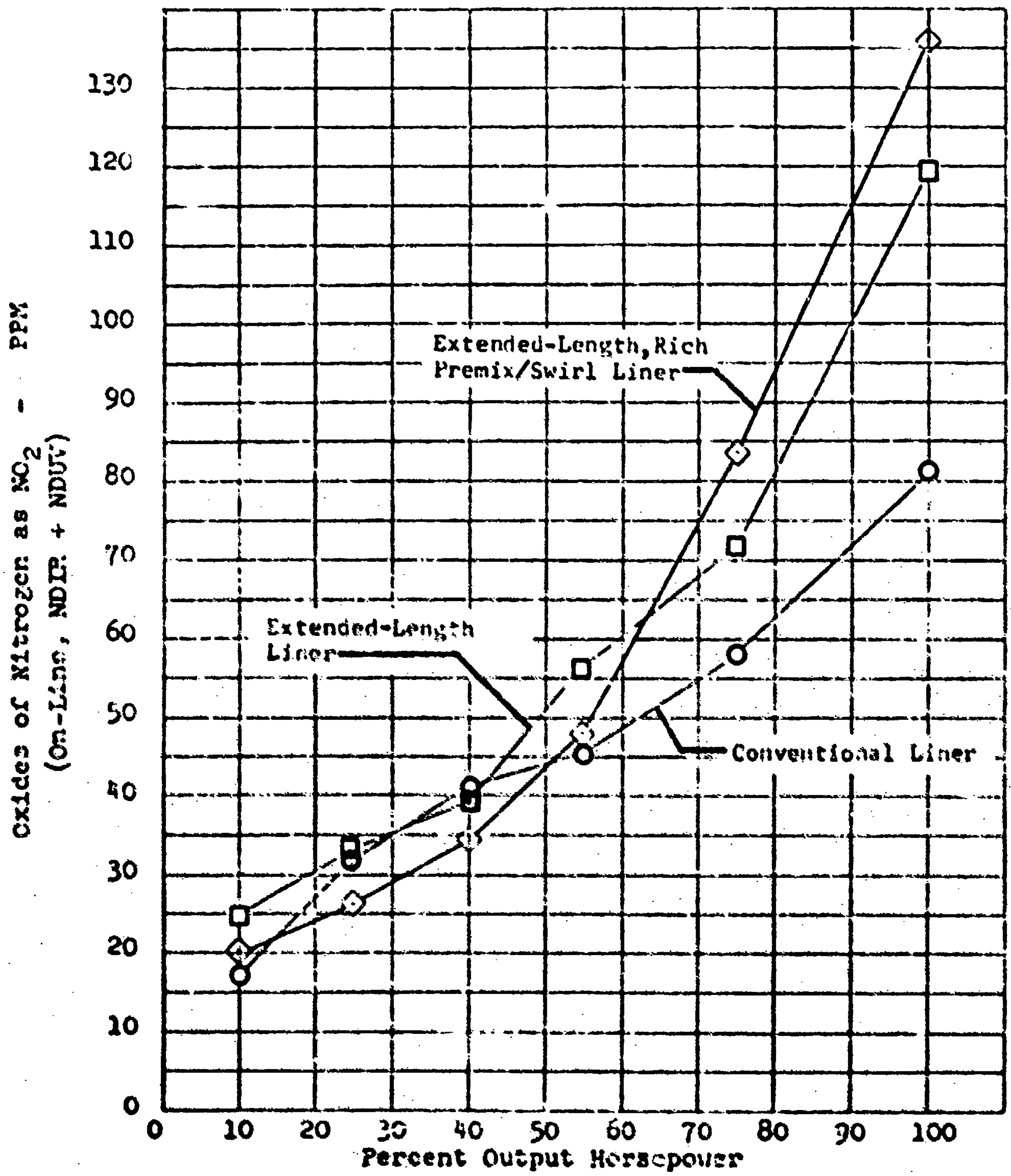


Figure 191. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Rich Premix/Swirl Combustor and T63 Baseline Combustors.

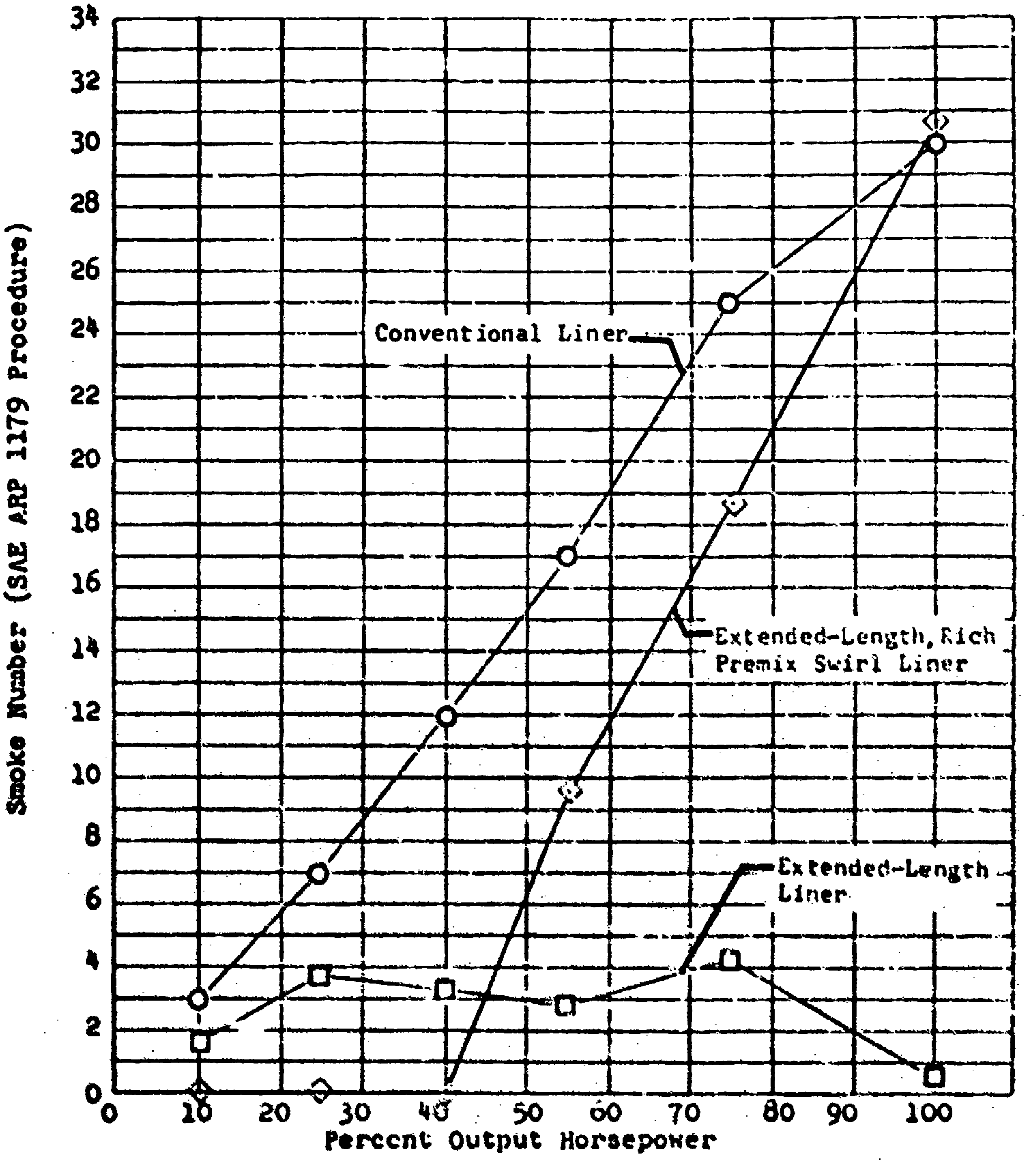


Figure 192. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Rich Premix/Swirl Combustor and T63 Baseline Combustors.

The temperature profile (T_{max}/T_{avg}) from the "Extended-Length, Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" was approximately the same as from the "Conventional Liner" at 10%, 25%, and 40% power conditions. However, as shown in Figure 193, it was worse than from the "Conventional Liner" at 55%, 75%, and 100% power conditions.

The measured pressure loss of the "Extended-Length,Premix Cup/ Liquid Fuel/Swirl-Dome Combustor Liner" was nominally 7.4%. This compares, as shown in Table LXV, to 4.6% for the "Conventional Liner" and 5.1% for the "Extended-Length Liner."

Using the emission data presented in Table LXV and Figures 189 through 192, the emission index for the selected LOH duty cycle was calculated. The total emission index for the "Extended-Length Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" was 9.087 lb emissions/1000 lb fuel. This compares to 32.945 lb/1000 lb fuel for the "Conventional Liner." Therefore, as shown in Table XLVI, the total emissions from the "Extended-Length,Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" were 28% of the emissions from the "Conventional Liner" and met this part of the contract objectives. However, as shown in Table XLVI, the NO_x emission index compared to the "Conventional Liner" NO_x emission index increased and did <u>not</u> meet the contract objective. For the same length liner, the "Extended-Length,Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" did provide a very slight improvement in NO_x, as shown in Table XLVI.

Visual examination of the combustor liner after the tests did <u>not</u> reveal any apparent damage.

The "Extended-Length,Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner" gave a 72% reduction in total emission compared to the "T63 Conventional Liner." However,the NO_x increased 21% (this increase was offset by CO, H/C, and particulate reductions to give the total reduction of 72%). This increase in NO_x could be controlled by variable geometry,and the total emissions would also decrease even more than the 72%. This is due to the unique slope of the CO emission curve shown in Figure 189. Normally, the NO_x is traded off for an increase in CO. However,with the "Extended-Length,Premix Cup/Liquid Fuel/Swirl-Dome Combustor Liner," both CO and NO_x would decrease with variable-geometry control of the primary zone fuel/air ratio.

PEPPER-POT DOME COMBUSTOR

One of the potential concepts selected from the Task 2 studies and partial results from Task 3 was the "Extended Length-Pepper-Pot Dome Combustor Liner." The concept was to incorporate the following

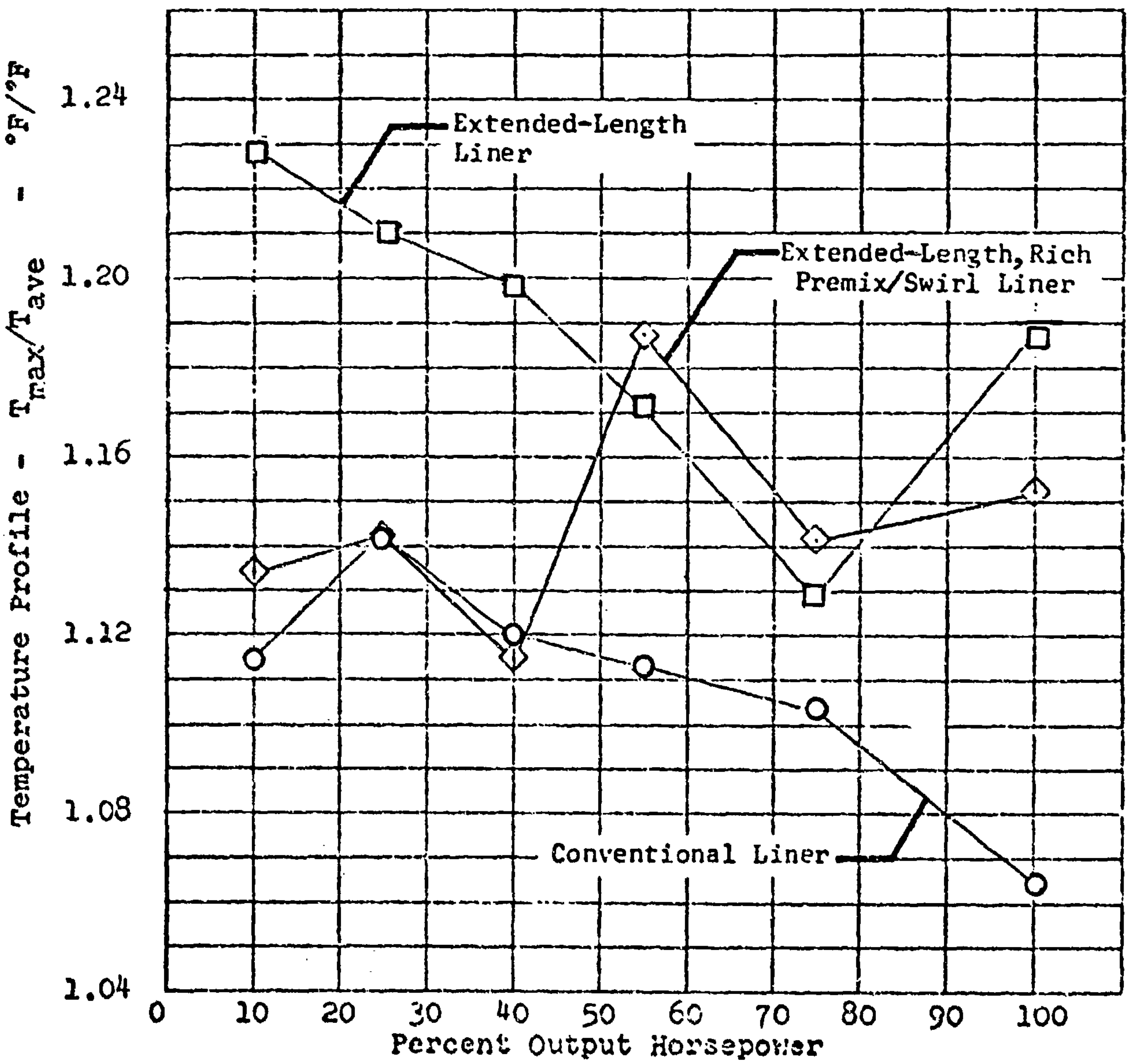


Figure 193. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Rich Premix/Swirl Combustor and T63 Baseline Combustors.

TABLE LXV. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH, PREMIX CUP/SWIRL-DOME LINER

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.128
III. Extended-Length, Premix Cup/Swirl-Dome Liner						
A. Emissions						
CO, (ppm)	18.6	21.6	26.1	40.7	67.3	78.7
H/C, (ppm)	.7	.4	.5	.2	.7	.1
NO_x, (On-Line, NDIR & NDUV) (ppm)	20.0	26.0	34.5	48.0	84.0	136.0
NO_x, (Saltzman) (ppm)	19.0	29.1	31.7	--	--	--
Smoke Number	0.0	0.0	0.0	9.62	18.69	30.74
B. Pressure Loss (%)	7.42	7.04	7.04	7.03	6.42	6.31
C. Temp. Profile (T_{max}/T_{Avg})	1.134	1.143	1.115	1.188	1.141	1.152

features to reduce the emissions:

- Small-scale recirculation with rapid conversion to plug flow. Task 2 reaction kinetic studies had shown that this would be an ideal condition for minimum CO, C_xH_y, and NO_x emissions.

- Convection cooling in the primary zone should be used instead of film cooling to avoid quenching of the CO, H/C, and C reactions in the relatively cold film air.

- Extended length would allow additional residence time to react the CO, H/C, and particulates. Previous reaction kinetic studies and experiments in Task 2 have shown that the extended length would significantly reduce CO and H/C emissions with a small increase in NO_x emissions.

The "Extended-Length, Pepper-Pot Dome Combustor Liner" was designed for the T63 nonregenerative combustor operating conditions tabulated in Table IV.

A completely redesigned primary zone was fabricated to obtain the "Extended-Length, Pepper-Pot Dome Combustor Liner." As shown in Figure 194, the only part of the conventional T63 liner retained in the design was the dilution zone section. The "Extended-Length, Pepper-Pot Dome Combustor Liner," as shown in the external view (Figure 195), has the following characteristics:

- The total length is 15.56 inches compared to 9.56 inches for the conventional T63 liner. (See Figure 194.)

- The fuel injector was the standard T63 dual-orifice, pressure atomizer.

- All the primary air was admitted through the dome holes as shown in Figure 194.

- The primary zone was convection cooled as shown in Figure 194 instead of the conventional film cooling.

- The airflow distribution was designed for 0.77 equivalence ratio in the primary zone at T63 nonregenerative maximum power conditions. This is the same as the T63-A-5A Conventional Combustor.

The "Extended-Length, Pepper-Pot Dome Combustor Liner" was tested at the conditions tabulated in Table IV. The tests were conducted at steady-state conditions, in the DDA Combustion Research Laboratory, using JP-4 fuel.

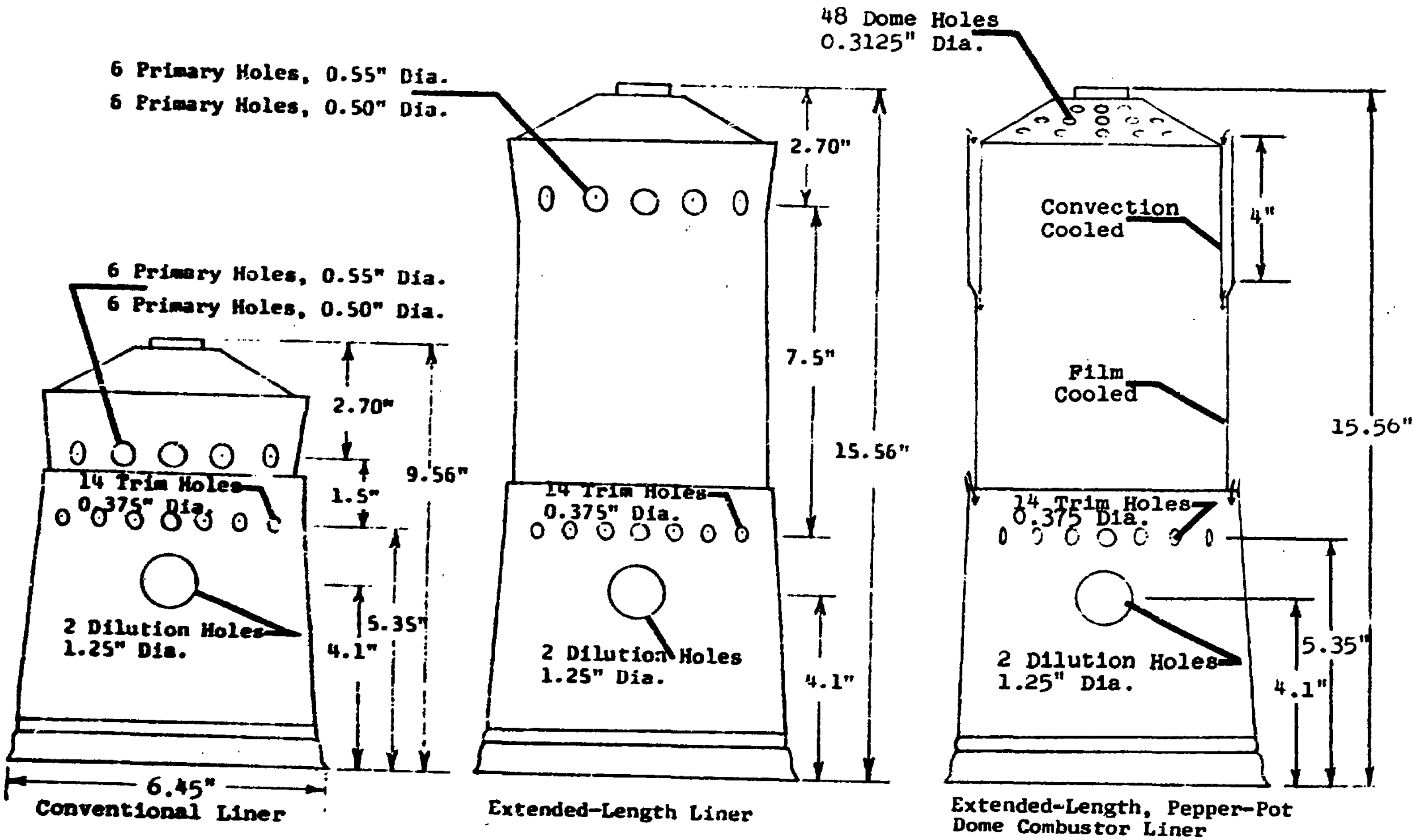


Figure 194. Hole Pattern and Size Comparison of Liners.

Figure 195. Preliminary Low-Emission Extended-Length, Pepper-Pot-Dome Combustor Liner.

The CO and H/C emission results, plotted in Figure 196 and 197, respectively, show significant reductions in emissions compared to the "Conventional T63-A-5A Liner." Compared to the same length combustor, "Extended-Length Liner," the CO and H/C emissions were less at low-power conditions. However, at power settings above 55%, for the CO and H/C emissions were higher than for the "Extended-Length Liner." The NO_x results, presented in Figure 198, show higher NO_x emissions than with the "Conventional Combustor" and approximately the same as with the "Extended-Length Liner." The smoke was significantly reduced, as shown in Figure 199, compared to either the "Conventional Liner" or the "Extended-Length Liner."

The temperature profile (T_{max}/T_{avg}) from the "Extended-Length, Pepper-Pot Dome Combustor Liner", as shown in Figure 200, was worse than from the "Conventional Liner" but better than from the "Extended-Length Liner." With development, the temperature profile could probably be improved to equal the "Conventional Liner."

The measured pressure loss of the "Extended-Length, Pepper-Pot Dome Combustor Liner" was nominally 5.28%. This compares, as shown in Table LXVI, to 4.4% for the "Conventional Liner" and 4.8% for the "Extended-Length Liner."

Using the emission data presented in Table LXVI and Figures 196 through 199, the emission index for the selected LOH duty cycle was calculated. The total emission index for the "Extended-Length, Pepper-Pot Dome Combustor Liner" was 16.083 lb emission/1000 lb fuel. This compares to 32.945 lb/1000 lb fuel for the "Conventional Liner." Therefore, as shown in Table XLVI, the total emissions from the "Extended-Length, Pepper-Pot Dome Combustor Liner" were 49% of the emissions from the "Conventional Liner" and met this part of the contract objectives. However, as shown in Table XLVI, the NO_x emission index compared to the "Conventional Liner" NO_x emission index increased and did not meet the contract objective. For the same length liner ("Extended Length"), the "Extended-Length, Peppar-Pot Dome Combustor Liner" had approximately the same total emissions but a major reduction in particulates (smoke).

Visual examination of the combustor liner after the tests did not reveal any apparent damage.

The "Extended-Length, Pepper-Pot Dome Combustor Liner" gave a 51% reduction in total emission compared to the "T63 Conventional Liner." However, the NO_x increased 33% (this increase was offset by CO, H/C, and particulate reductions to give the total reduction of 51%). This increase in NO_x could be controlled by variable geometry. However, the CO and C_xH_y emissions would then increase.

Additional improvements in emissions from this combustor might be

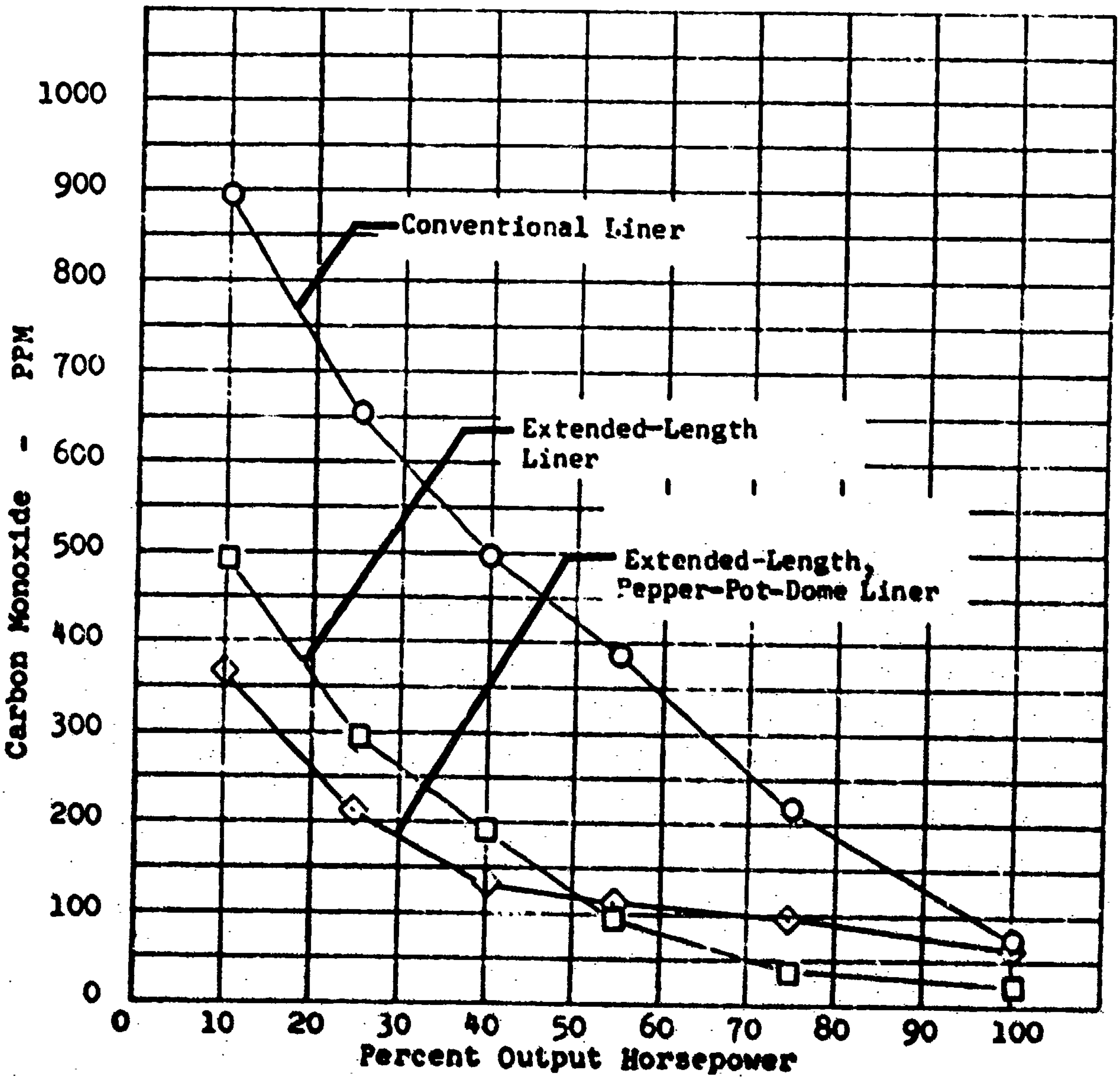


Figure 196. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Pepper-Pot-Dome Combustor and T63 Baseline Combustors.

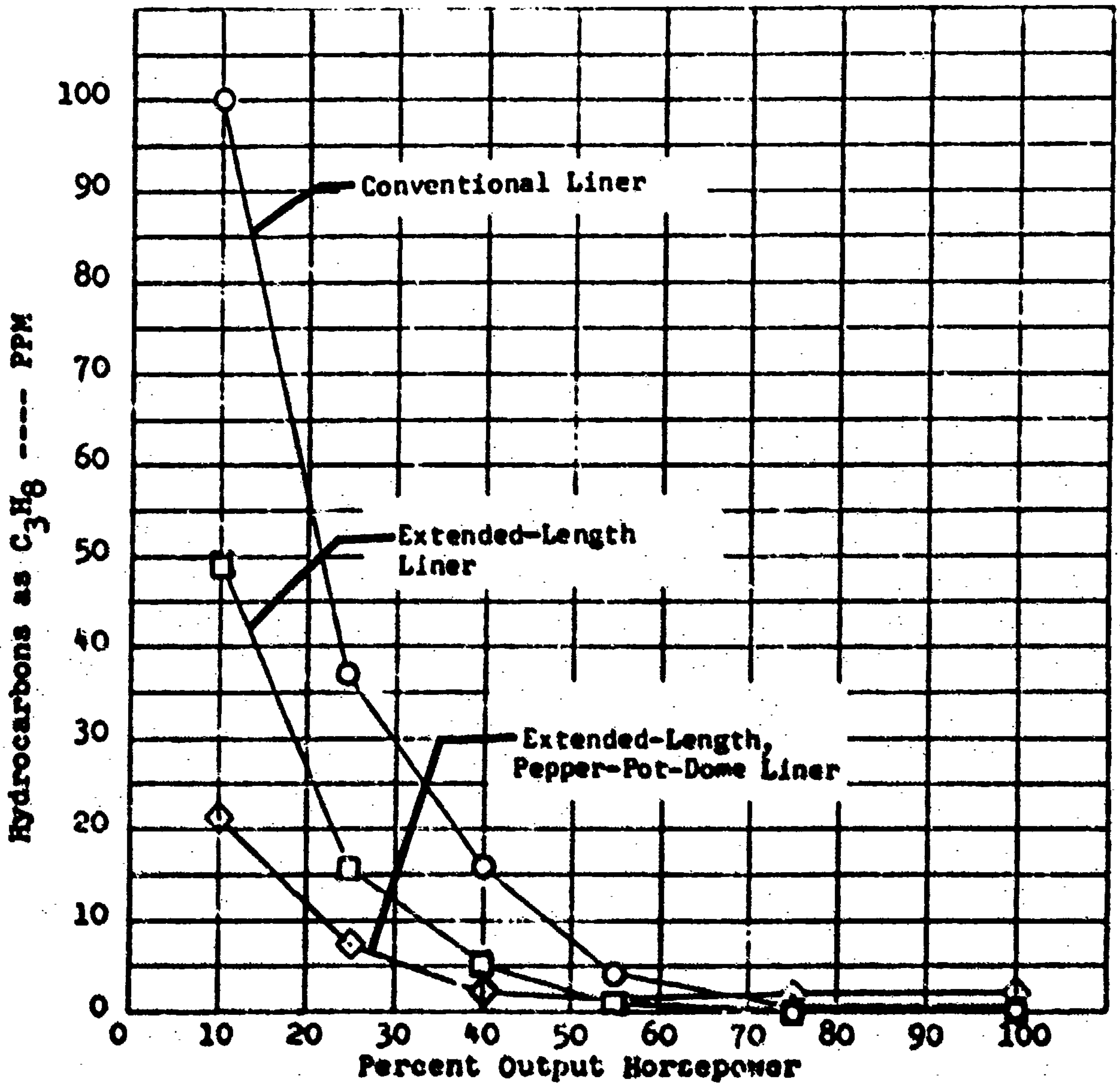


Figure 197. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Pepper-Pot-Dome Combustor and T63 Baseline Combustors.

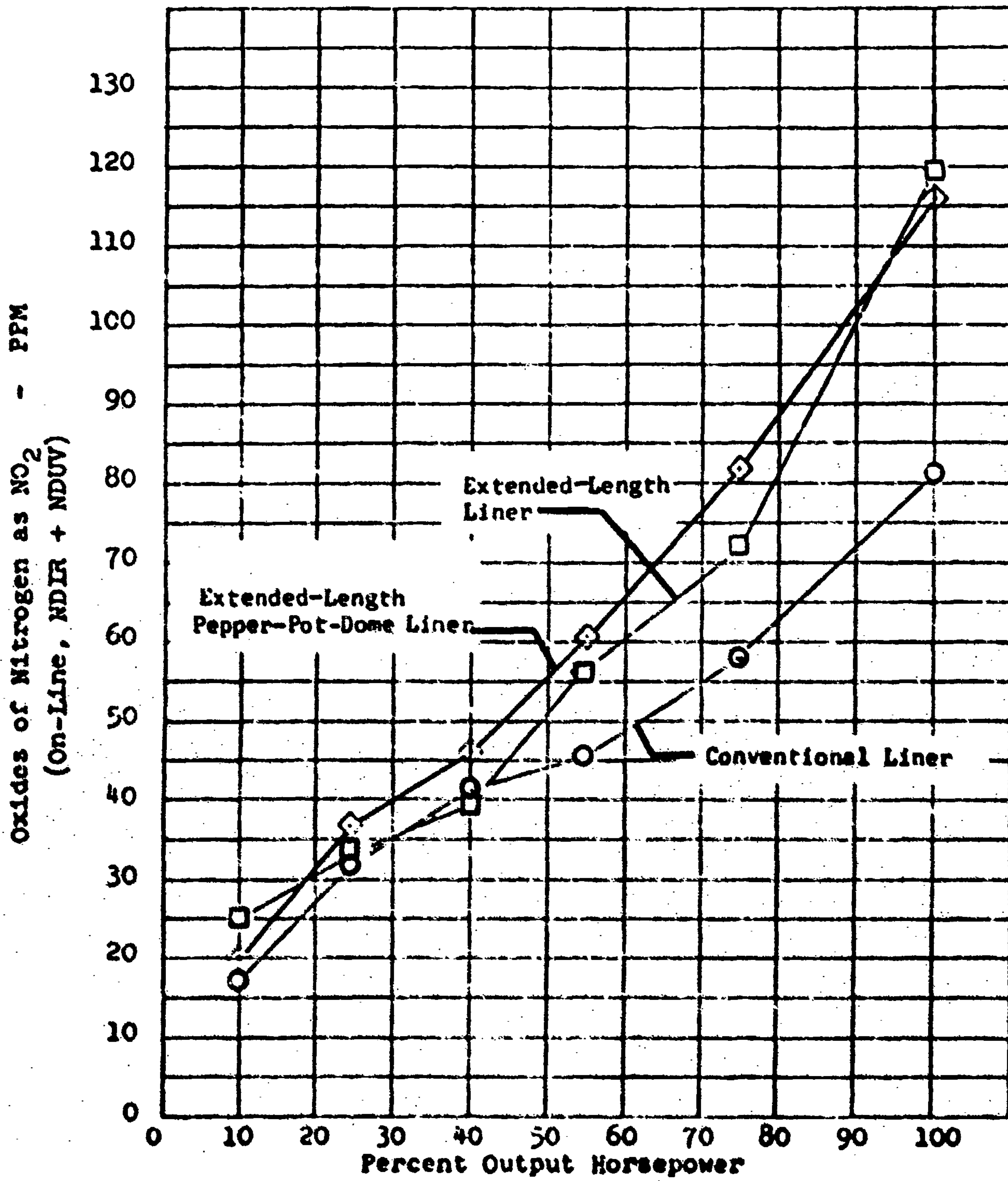


Figure 198. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Pepper-Pot-Dome Combustor and T63 Baseline Combustors.

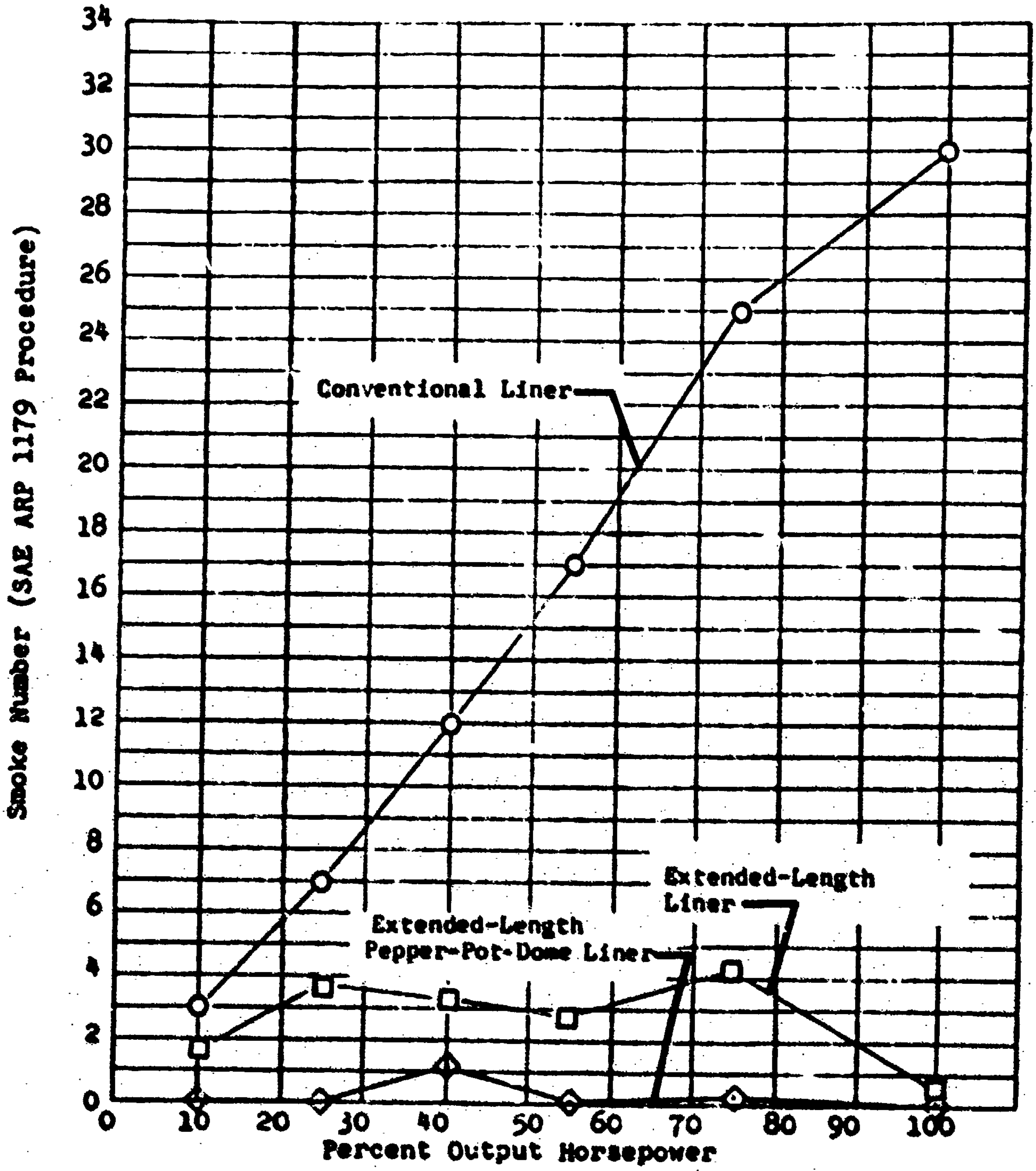


Figure 199. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Pepper-Pot-Dome Combustor and T63 Baseline Combustors.

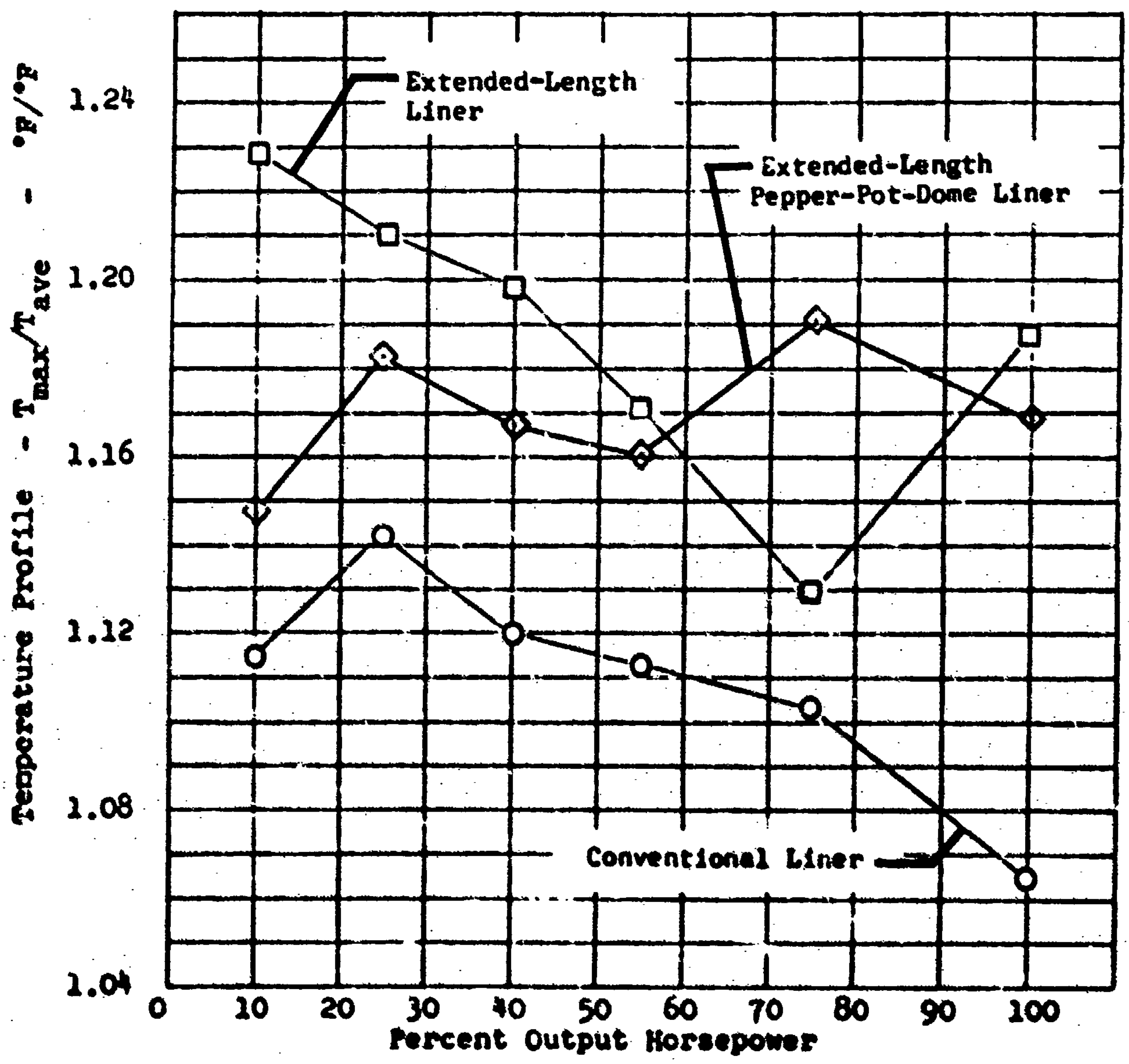


Figure 200. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Pepper-Pot-Dome Combustor and T63 Baseline Combustors.

TABLE LXVI. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, (3) EXTENDED-LENGTH, PEPPER-POT DOME LINER

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.[illegible]
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.92	4.70	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.183
III. Extended-Length Pepper-Pot Dome Liner						
A. Emissions						
CO, (ppm)	382.5	209.6	135.2	112.4	99.1	66.8
H/C, (ppm)	21.0	7.5	2.3	1.1	1.7	1.9
NO_x, (On-Line, NDIR & NDUV) (ppm)	20.0	36.5	46.0	60.5	82.0	116.0
NO_x, (Saltzman) (ppm)	22.6	--	--	--	--	--
Smoke Number	0.6	0.0	1.17	0.07	0.24	0.01
B. Pressure Loss (%)	5.63	5.22	5.32	5.44	5.30	4.82
C. Temp. Profile (T_{max}/T_{Avg})	1.148	1.182	1.168	1.160	1.191	1.169

obtained by further "tailoring" of the fuel spray angle with the dome slope angle.

The most outstanding feature of the "Extended-Length, Pepper-Pot Dome Combustor Liner" was the 99% reduction in particulates (smoke). This low smoke feature could have immediate application in combustors which require smoke control.

DELAYED QUENCH COMBUSTOR

One of the additional concepts selected during the Task 3 experimental studies was the "Extended-Length, Delayed-Quench Combustor Liner." The concept was based on the results of the "Extended-Length, Early-Quench Combustor Liner", which showed that when the primary holes were moved closer to the dome for earlier quenching, the CO, C_xH_y, NO_x, and particulates all increased. The "Extended-Length, Delayed-Quench Combustor" incorporated the following features to reduce emissions:

- Delayed primary air quench to further evaluate the effect of axial location of the primary air on combustor performance and emissions.

- Extended length to allow additional residence time to react the CO, C_xH_y, and particulates. Previous reaction kinetics studies and experiments in Task 2 had shown that the extended length would significantly reduce CO and C_xH_y emissions with a small increase in NO_x emissions.

The modifications made to the conventional liner to obtain an "Extended-Length, Delayed-Quench Liner" were:

- Add constant-diameter, 6-inch-long section between the primary holes and the film coolant step.

- Close original row of primary holes.

- Add new row of primary holes (same as original, T63 conventional), in new location, which is 1.10 inches farther from the dome than the conventional.

The hole patterns and sizes for the "Extended-Length, Delayed-Quench Liner," "Conventional Liner," and "Extended Length Liner" are shown in Figure 201. All three liners had the same airflow area split as tabulated below.

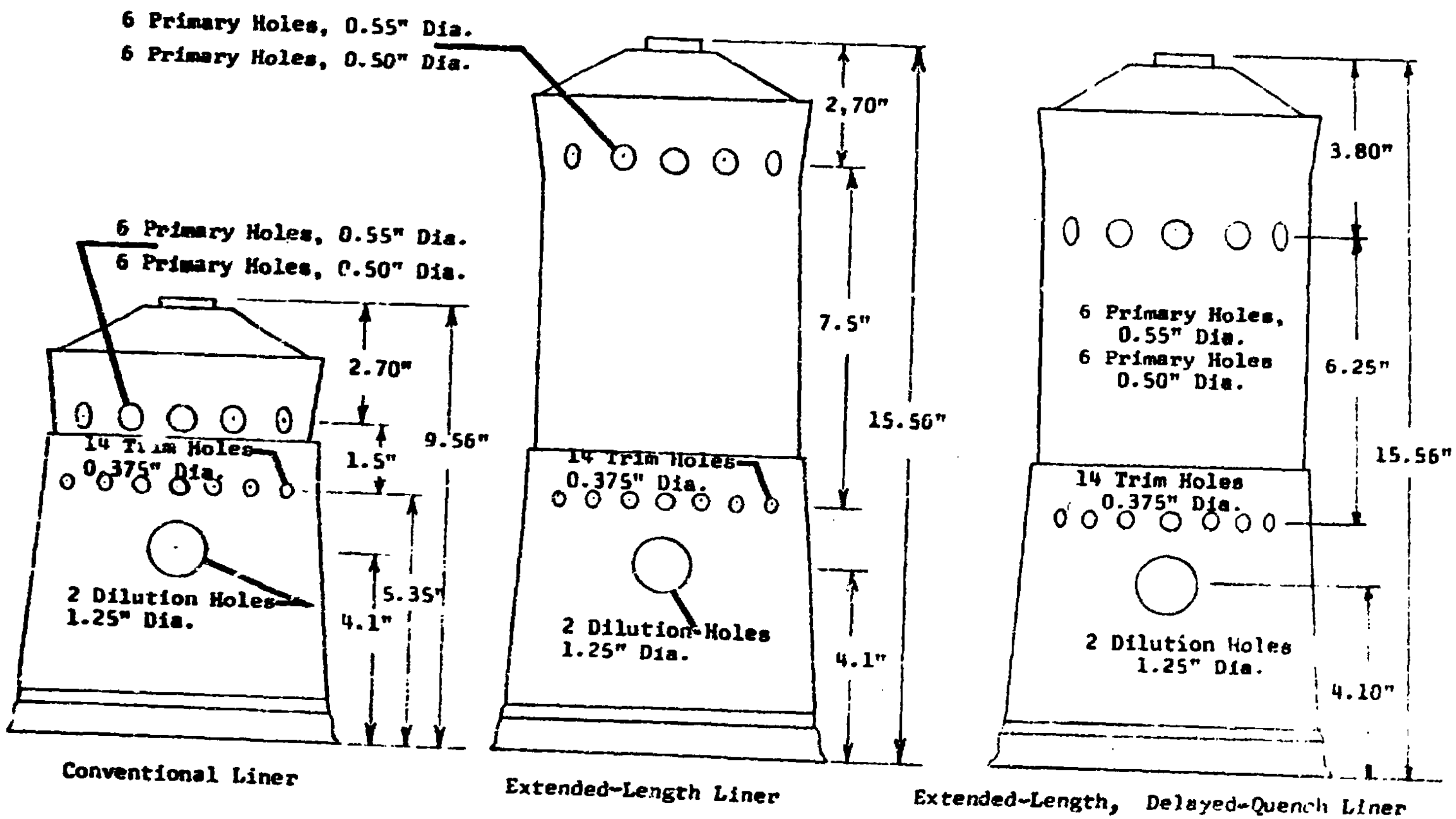


Figure 201. Hole Pattern and Size Comparison of Liners.

Dome Holes	11.8%
First Cooling Step.............	11.2%
Primary Holes	26.3%
Second Cooling Step	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above calculated flow splits, the primary zone equivalence ratio at T63 maximum power is 0.77.

The "Extended-Length,Delayed-Quench Liner" was tested in the T63 combustor rig at the nonregenerative T63 combustor conditions tabulated in Table IV. The tests were conducted at steady-state conditions using JP-4 fuel. The emission, pressure loss, and temperature profile results are summarized and compared with the "Conventional T63-A-5A Liner" and the "Extended-Length Liner" in Table LXVII. The data summary in Table LXVIII compares the three axial positions of primary holes in extended-length configurations: "Extended-Length,Early-Quench," "Extended Length," and "Extended-Length,Delayed-Quench." All four liners were tested with the conventional T63 pressure atomizing fuel injector and JP-4 fuel.

Carbon monoxide, hydrocarbon, oxides of nitrogen, and smoke emission results for the "Extended-Length,Delayed-Quench Liner," the "Extended-Length,Early-Quench Liner," the "Extended-Length Liner," and the "Conventional Liner" are plotted in Figures 202 through 205. Comparison of the emission data in these figures shows:

- The CO and C_xH_y emissions were all below the concentration levels of the "Conventional T63-A-5A Liner" but above the levels of the "Extended-Length Liner." These emissions were also below the "Extended-Length,Early-Quench Liner" levels.
- The NO_x emissions as measured with NDIR and NDUV instruments were equal to or lower than the concentration levels of the "Conventional T63-A-5A Liner" at low power levels, but they were higher at 75% and 100% power points. Compared to the "Extended-Length Liner," the NO_x was lower; but for the "Extended-Length,Early-Quench," the NO_x emissions were about the same based on NDIR + NDUV data.
- The smoke data comparison in Figure 205 reveals a marked

TABLE LXVII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL COMBUSTOR, (2) EXTENDED-LENGTH COMBUSTOR, (3) EXTENDED-LENGTH, DELAYED-QUENCH COMBUSTOR

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	9.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended-Length, Delayed-Quench Liner						
A. Emissions						
CO, (ppm)	587.4	426.5	281.3	170.9	97.2	38.6
H/C, (ppm)	55.0	22.0	7.2	2.1	.9	.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	23.5	29.5	37.0	46.5	67.5	103.0
NO_x, (Saltzman) (ppm)	23.5	34.4	--	--	--	112.0
Smoke Number	29.72	41.62	43.88	51.10	43.71	40.31
B. Pressure Loss (%)	4.74	4.55	4.85	4.55	4.54	4.46
C. Temp. Profile (T_{max}/T_{avg})	1.143	1.174	1.173	1.157	1.229	1.239

TABLE LXVIII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) EXTENDED-LENGTH, DELAYED-QUENCH LINER, (2) EXTENDED-LENGTH, CONVENTIONAL-QUENCH LINER, AND (3) EXTENDED-LENGTH, EARLY-QUENCH LINER.

	Cycle Point					
	1	6	5	4	3	2
I. Extended-Length, Delayed-Quench Liner						
A. Emissions						
CO, (ppm)	587.4	426.5	281.3	170.9	97.2	38.6
H/C, (ppm)	55.0	22.0	7.2	2.1	.9	.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	23.5	29.5	37.0	46.5	67.5	103.0
NO_x, (Saltzman) (ppm)	23.5	34.4	--	--	--	112.0
Smoke Number	29.72	41.62	43.88	51.10	43.71	40.31
B. Pressure Loss (%)	4.74	4.55	4.85	4.55	4.54	4.46
C. Temp. Profile (T_{max}/T_{avg})	1.143	1.174	1.171	1.157	1.229	1.239
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended-Length, Early-Quench Liner	Blow-Out					
A. Emissions						
CO, (ppm)		465.2	389.9	257.6	139.	56.7
H/C, (ppm)		120.0	38.0	10.4	2.1	1.2
NO_x, (On-Line, NDIR & NDUV) (ppm)		27.5	35.0	42.0	68.0	111.5
NO_x, (Saltzman) (ppm)		29.0	42.8	57.1	82.6	124.1
Smoke Number			11.5	12.9	20.5	22.5
B. Pressure Loss (%)		4.59	4.91	4.78	4.68	4.36
C. Temp. Profile (T_{max}/T_{avg})		1.3023	1.206	1.2519	1.1938	1.1611

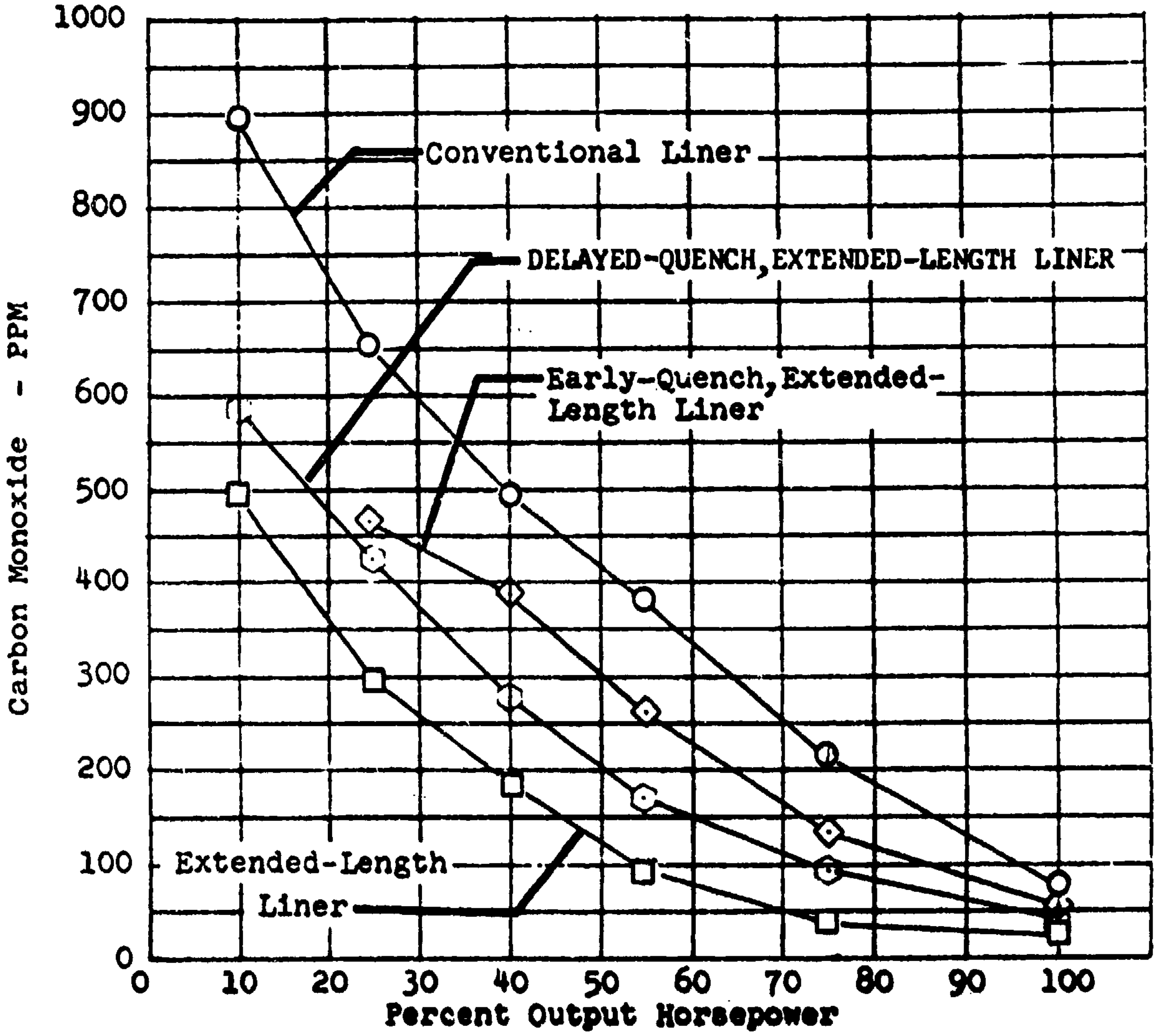


Figure 202. Nonregenerative T63-A-5A Combustor Carbon Monoxide Data Comparison for Conventional Liner, Extended-Length Liner, Early-Quench, Extended-Length Liner, Delayed-Quench, Extended-Length Liner.

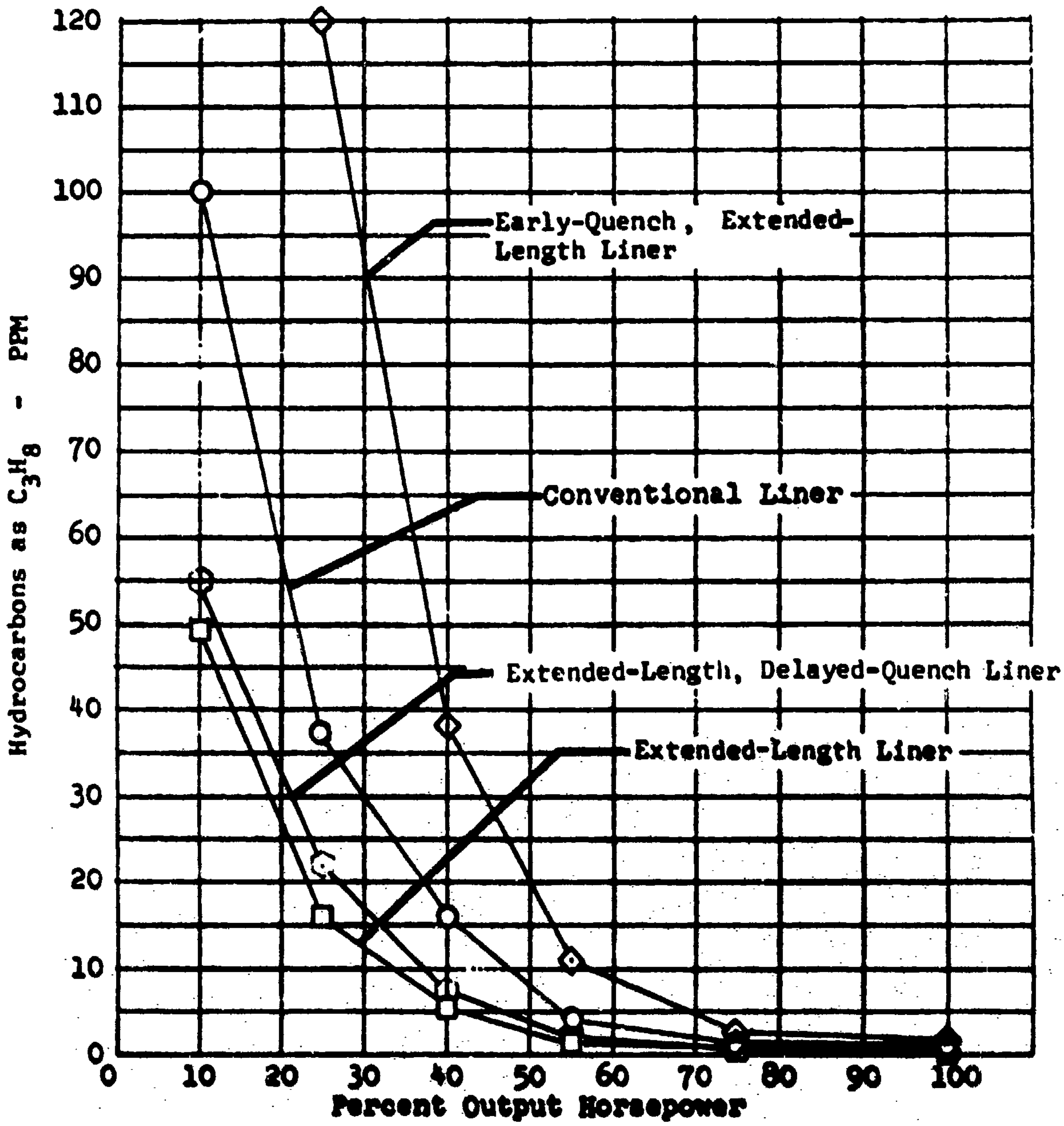


Figure 203. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Conventional Liner, Extended-Length Liner, Early-Quench Liner, Extended-Length, Delayed-Quench Liner.

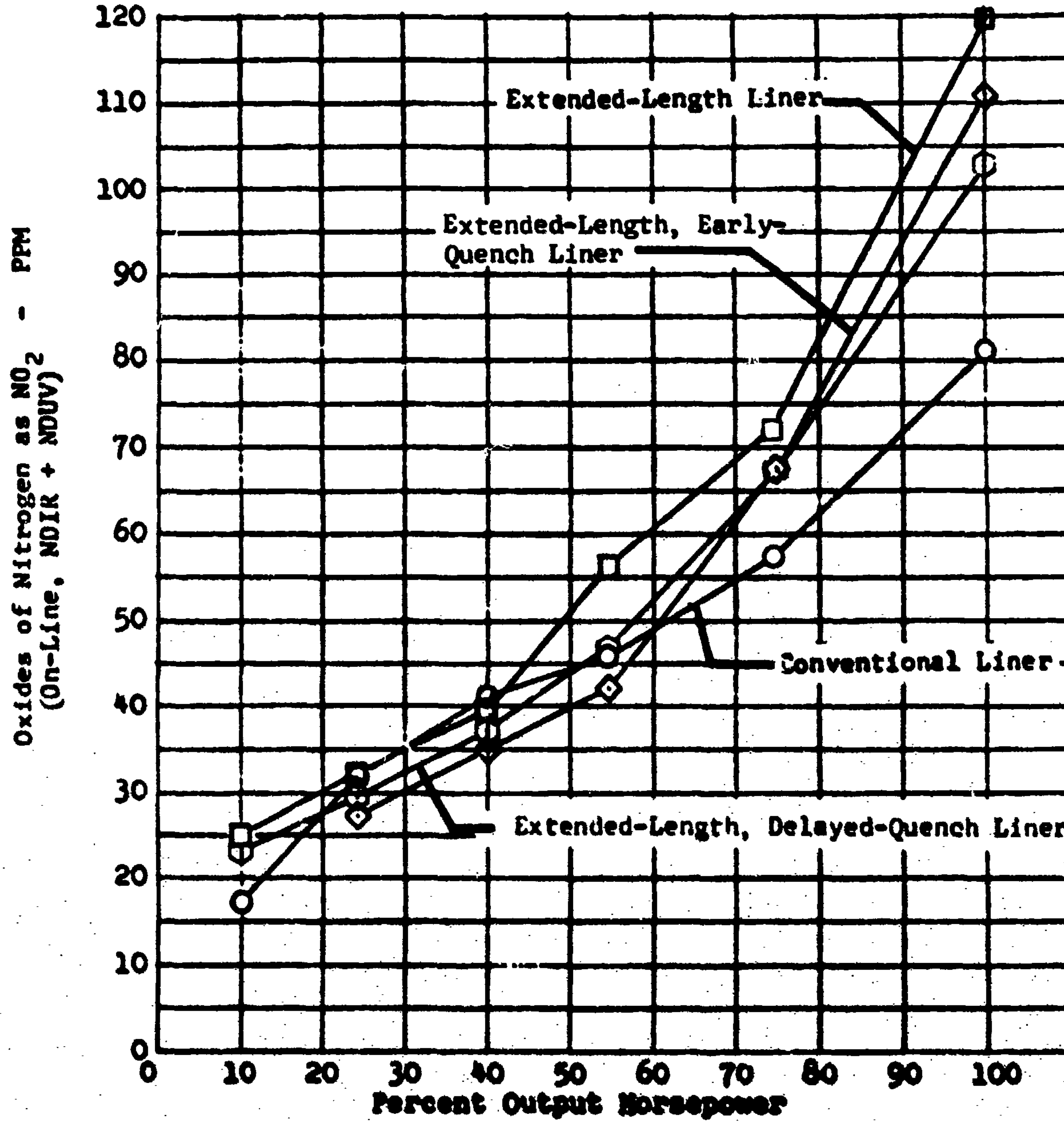


Figure 204. Nonregenerative T63-A-5A Combustor
Oxides of Nitrogen Data Comparison for Conventional Liner, Extended Length Liner, Early Quench Liner, Extended-Length, Delayed-Quench Liner.

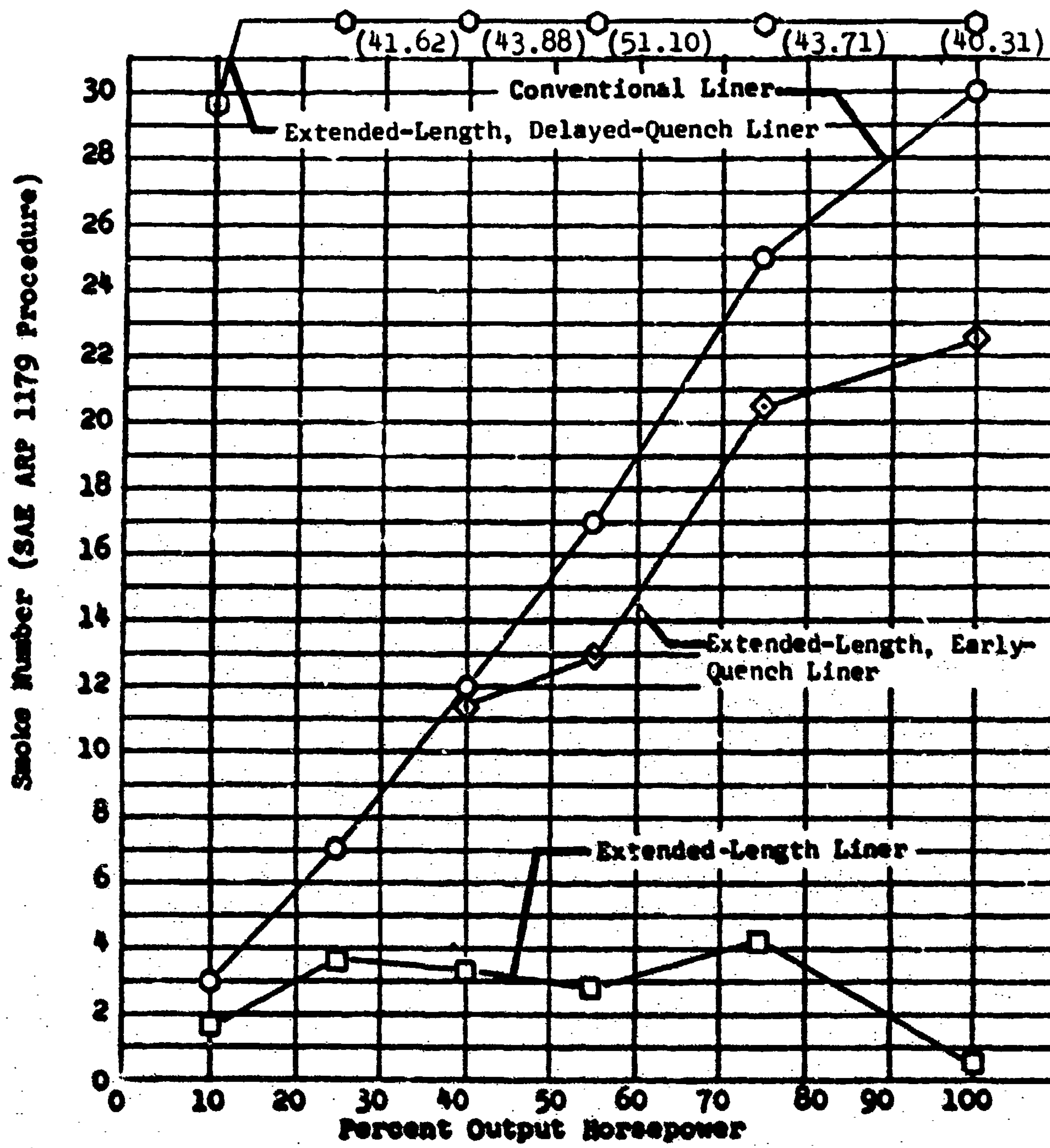


Figure 205. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Conventional Liner, Extended-Length Liner, Early-Quench Liner, Extended-Length, Delayed-Quench Liner.

increase in smoke/particulates, higher than any of the other three liners. The "Early-Quench Liner" produced less smoke than the "Delayed-Quench Liner," but both produced significantly more smoke than the "Extended-Length Liner" with its standard quench primary.

Using the emission data presented in Tables LXVII and LXVII and Figures 202 through 205, an emission index (EI) for the selected LOH duty cycle was calculated. The total duty cycle EI for the "Extended-Length, Delayed-Quench Combustor Liner" was 21.193 lb emissions/1000 lb fuel. This compares with 32.945 lb/1000 lb fuel for the "Conventional Liner" and 15.718 lb/1000 lb fuel for the "Extended-Length Liner." Therefore, as shown in Table XLVI, the total emissions from the "Extended-Length, Delayed-Quench Combustor Liner" were 64% of the emissions from the "Conventional Liner." Compared to the "Extended-Length Liner," the effect of delayed quench was to increase the total emissions from 48% of baseline to 64%, which is a relative increase of 33%.

The temperature profile (T_{max}/T_{avg}) from the "Extended-Length, Delayed-Quench Combustor Liner" was worse than the "Conventional Liner" at all power levels, see Figure 206. It had a better temperature profile than either the "Early-Quench Liner" or the "Extended-Length, Standard-Quench Liner" for operating conditions up to 55% power. At 75% and 100% power conditions, its temperature profile was the worst of the three extended-length combustors.

The average measured pressure loss of the "Extended-Length, Delayed-Quench Combustor Liner" was 4.62% for the six data points. This compares to average pressure losses of 4.44% for the "Conventional Liner" and 4.84% for the "Extended-Length Liner."

Visual examinations of the combustor liner after the test did <u>not</u> reveal any apparent damage.

The "Extended-Length, Delayed-Quench Liner" gave only a 36% reduction in total emissions compared to the "Conventional T63-A-5A Combustor Liner." However, compared to the "Extended-Length, Standard-Quench Combustor Liner," the total emissions increased 33%. Thus, when also considering the emission results from the "Extended-Length, Early-Quench Combustor Liner," moving the axial location of the primary air holes either upstream (early-quench) or downstream (delayed-quench) increased the total emissions from the combustor and offered no performance advantages.

The delayed-quench approach tested for the T63 combustor did not improve the emissions, and its inclusion in the final concept is <u>not</u> recommended.

For best combustor performance, the axial locations of the primary

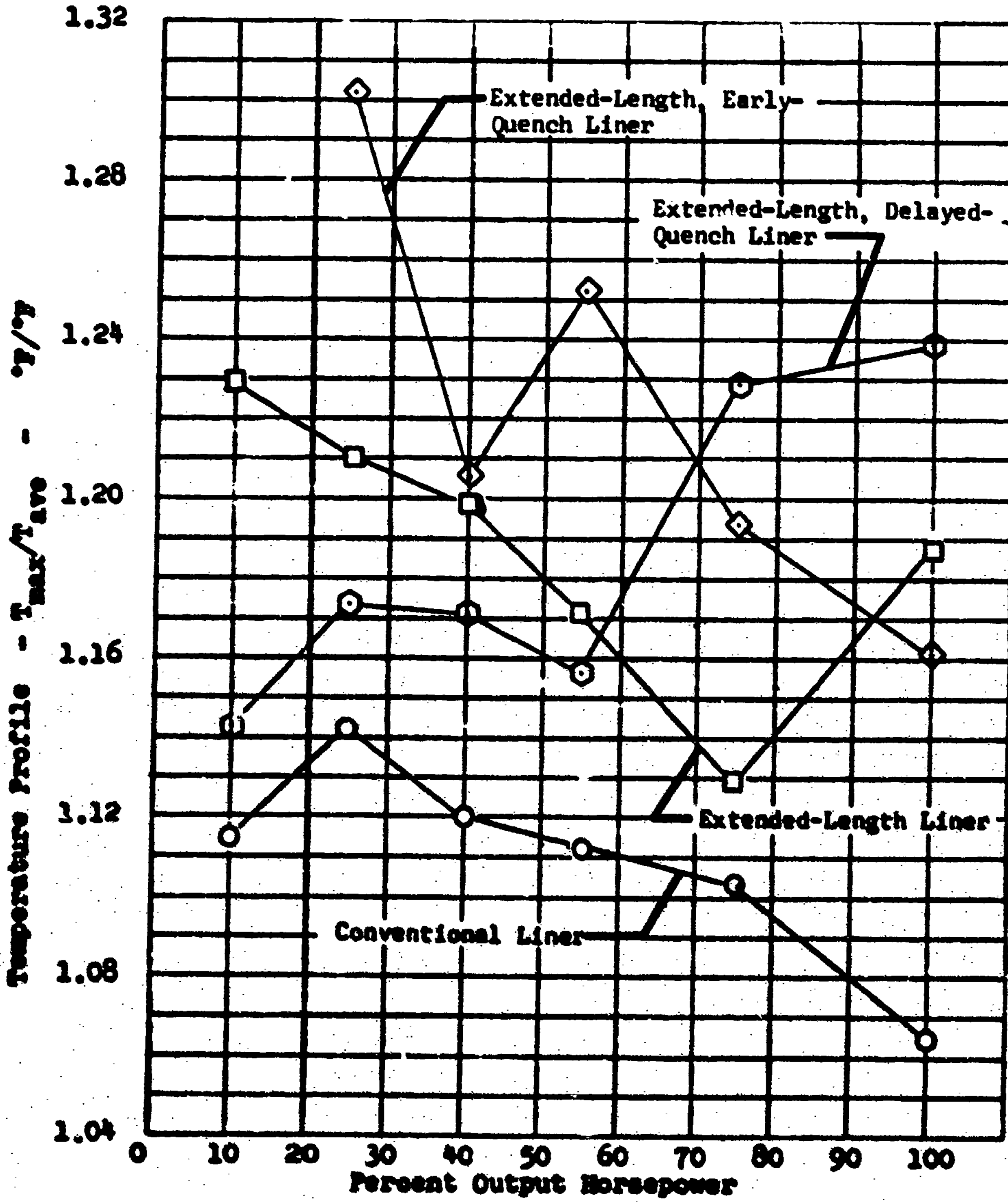


Figure 206. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Conventional Liner, Extended-Length Liner, Early-Quench Liner, Extended-Length, Delayed-Quench Liner.

air holes should be kept the same as they are in the "Conventional T63 Combustor Liner."

PREMIX/PREVAPORIZATION COMBUSTOR

One of the potential concepts selected (based upon the Task 2 studies, partial results from Task 3, and data from a GMC company-sponsored low-emission combustor program) for experimental evaluation was the "Extended-Length, Premix/Prevaporization Combustor Liner." This concept incorporates the following features to reduce the emissions:

- Premix/prevaporization tube section upstream of the primary section to (a) premix the fuel and primary air and (b) to prevaporize the fuel before the reaction zone. This premix/prevaporization feature was to improve combustion zone homogeneity and to avoid fuel droplet burning.

- Convection cooling instead of film cooling to avoid quenching of the CO, C_xH_y, and C. reactions in the relatively cold film air.

- Sudden expansion for flame stabilization.

- Lean primary zone to minimize NO_x formation.

- Delayed dilution to consume the CO, C_xH_y, and C pollutants.

The "Extended-Length, Premix/Prevaporization Combustor Liner" was obtained from a DDA, GMC company-sponsored program. The liner was designed for regenerative gas turbine engine applications. The fabricated liner is shown in Figure 207. The hole pattern and sizes are compared with those of the "Conventional Liner" in Figure 208. As illustrated in Figure 208, both liners had the same exit diameter of 6.21 inches. The length of the "Extended-Length, Premix/Prevaporization Combustor Liner" was 6.0 inches longer than the conventional T63 liner.

As shown in Figure 208 the total length of the primary zone plus the dilution zone was approximately equal to that for the Conventional and Premix/Prevaporization Liners.

Other design characteristics of the Premix/Prevaporization Liner as shown in Figures 207 and 208 were the following:

- A double-wall construction was used to provide convection cooling instead of the film cooling which was used in the conventional liner.

- A 6-inch-long premix/prevaporization tube was installed upstream of the primary section.

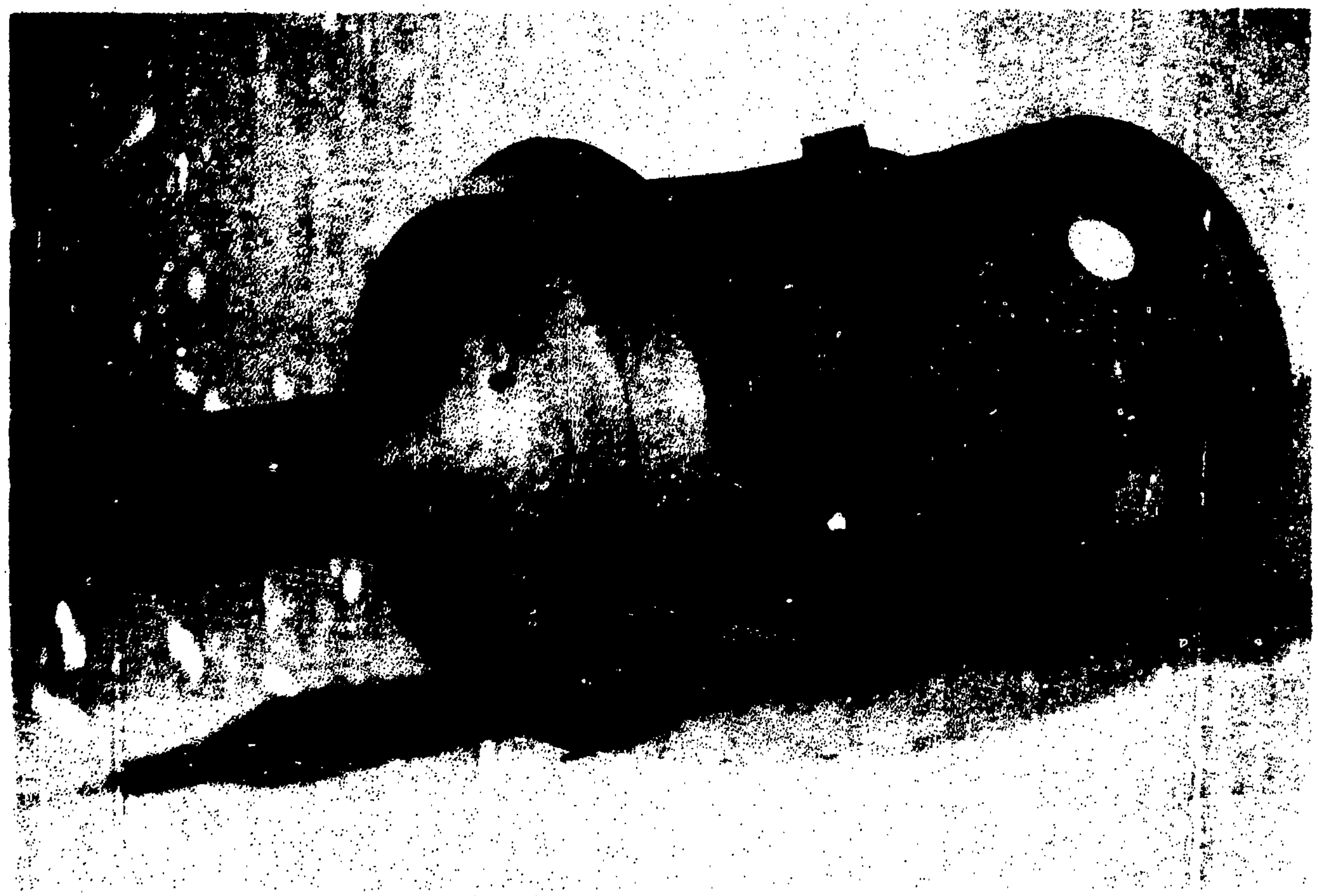


Figure 207. Preliminary Low-Emission, Extended-Length, Premix/Prevaporization Combustor Liner.

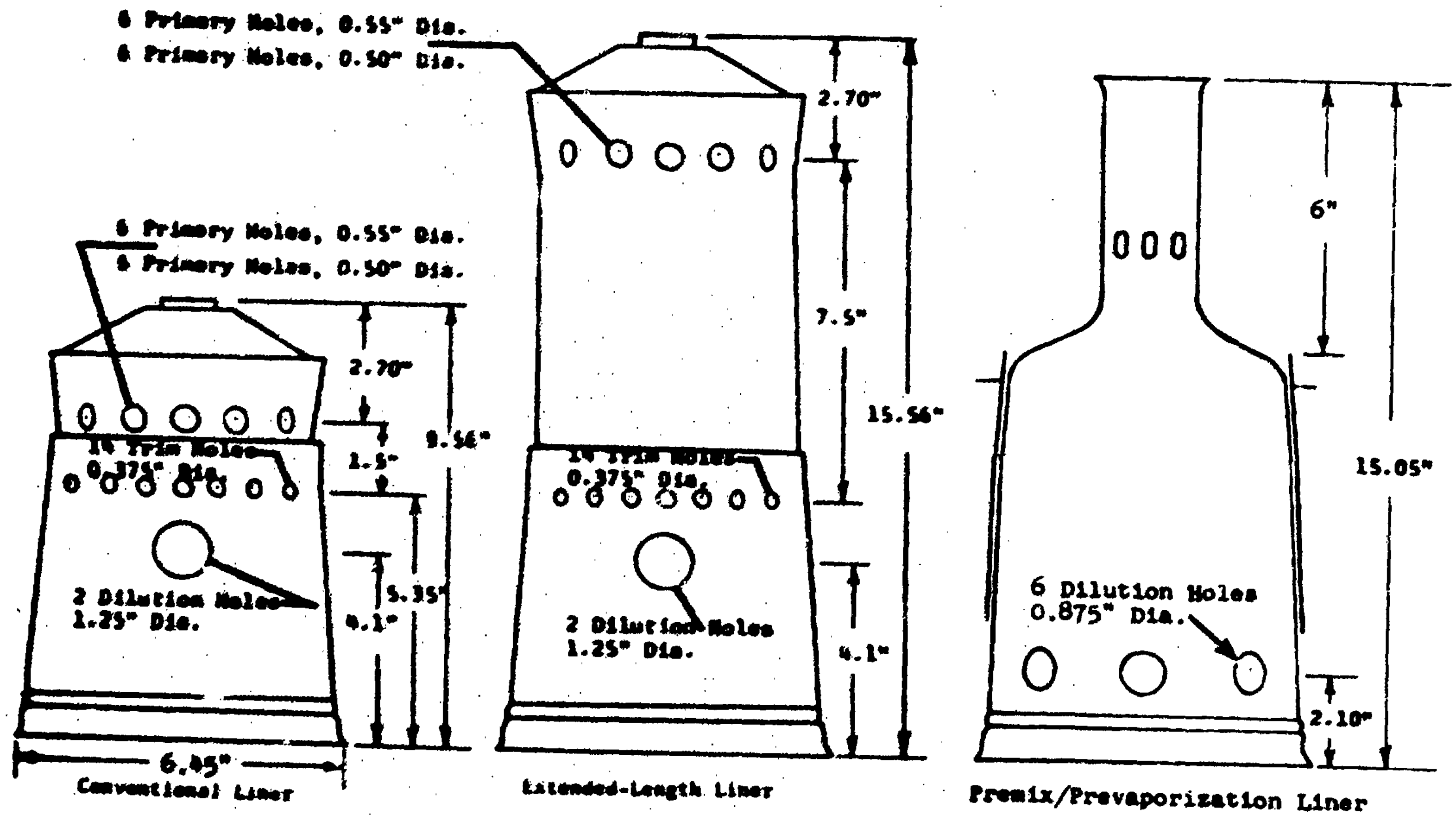


Figure 208. Hole Pattern and Size Comparison of Liners.

- The dilution holes were modified to change the size, number, and axial location. The main feature, in regard to emission performance, was to move the axial location 2 inches farther aft to increase the residence time for CO, C_xH_y, and C consumption.

- The calculated airflow to the primary section was 40% as compared to 38% in the Conventional and Extended-Length Liners. Thus, the equivalence ratio in the primary of 0.73 was slightly leaner than the 0.77 equivalence ratio in the T63 Conventional Liner.

The "Extended-Length, Premix/Prevaporization Combustor Liner" was tested with JP-4 fuel at:

- T63 nonregenerative, cycle point 5 conditions. As tabulated in Table IV, these conditions are: 2.53 lb/sec airflow rate, 397°F inlet air temperature, 63.7 psia inlet air pressure, and 0.0131 fuel/air ratio.

- T63 nonregenerative, cycle point 5 conditions except the fuel/air ratio was increased to 0.0145.

- T63 nonregenerative, cycle point 5 conditions except the fuel/air ratio was increased to 0.0185.

The latter two conditions were investigated because of the high CO and C_xH_y emissions at the design fuel/air ratio. This data at the higher fuel/air ratio would provide the emission performance trade-off data required to assess the potential of the premix/prevaporization approach if the liner were modified to change the primary/dilution airflow split.

Emission, pressure loss, and temperature profile for the "Conventional Liner," "Extended Length Liner" and "Premix/Prevaporization Liner" are compared in Table LXIX. As shown in this Table LXIX, the Premix/Prevaporization Liner had much higher total emissions than either of the other liners at the design fuel/air ratio. The CO and C_xH_y were considerably higher, but the NO_x was lower. This would indicate a very lean primary zone, and it was decided to increase the primary zone fuel/air ratio to establish the emission trade-off performance; i.e., allow the NO_x to increase to the Conventional Liner value and determine the effect on CO and C_xH_y. These tests were conducted at two additional fuel/air ratios of 0.0145 and 0.0185, and the results, presented in Table LXIX and Figure 209, show that substantial reductions were achieved in CO and C_xH_y with only moderate increases in NO_x. These emission performance trade-off comparisons show that the Premix/Prevaporization emission performance is better than that of the Conventional Liner, but probably not sufficient to meet the contract emission goals

TABLE LXIX. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE AT CYCLE POINT #5 (40% POWER) INLET CONDITIONS OF (1) CONVENTIONAL LINER, (2) EXTENDED-LENGTH LINER, AND (3) PREMIX/PREVAPORIZATION LINER

	Overall Fuel/Air Ratio					
			.0131	.0145	.0185	
I. Conventional Liner						
A. Emissions						
CO, (ppm)			496			
H/C, (ppm)			15.8			
NO_x, (On-Line, NDIR & NDUV) (ppm)			41.1			
NO_x, (On-Line, CL) (ppm)			32.6			
NO_x, (Saltzman) (ppm)			37.6			
Smoke Number			12.			
B. Pressure Loss (%)			4.53			
C. Temp. Profile (T_{max}/T_{avg})			1.120			
II. Extended Length Liner						
A. Emissions						
CO, (ppm)			185.5			
H/C, (ppm)			5.1			
NO_x, (On-Line, NDIR & NDUV) (ppm)			39.5			
NO_x, (On-Line, CL) (ppm)			35.0			
NO_x, (Saltzman) (ppm)			41.0			
Smoke Number			3.28			
B. Pressure Loss (%)			5.09			
C. Temp. Profile (T_{max}/T_{avg})			1.198			
III. Premix/Prevaporizer, Mod. B-1 Liner						
A. Emissions						
CO, (ppm)			1042.5	404.2	247.5	
H/C, (ppm)			600.0	60.0	14.4	
NO_x, (On-Line, NDIR & NDUV) (ppm)			14.5	18.0	49.0	
NO_x, (Saltzman) (ppm)			4.65	14.3	-	
Smoke Number			-	-	-	
B. Pressure Loss (%)			12.28	13.67	12.94	
C. Temp. Profile (T_{max}/T_{Avg})			1.198	1.135	1.240	

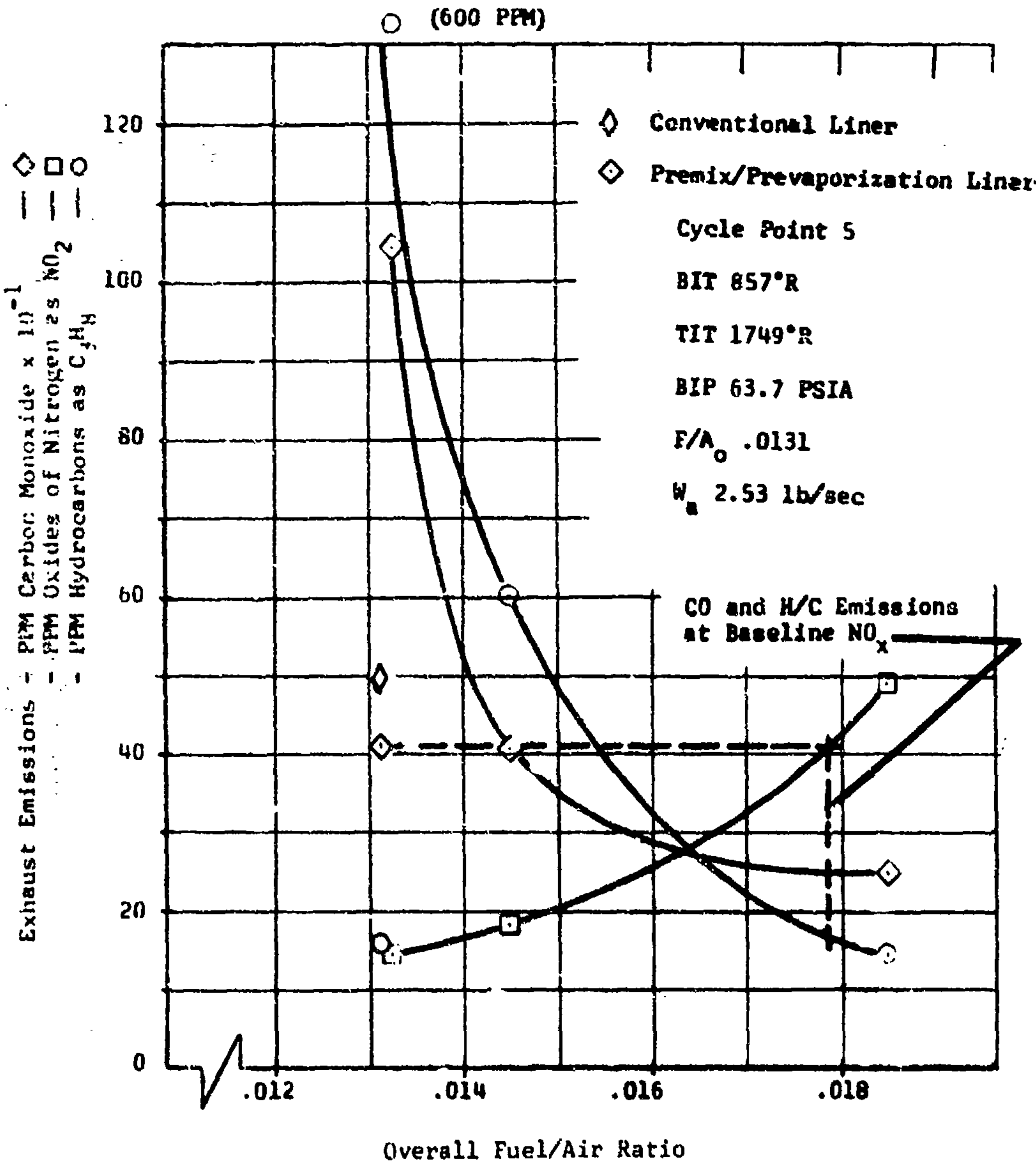


Figure 209. Exhaust Emissions at T63 Nonregenerative, Cycle Point (40% Power) Combustor Conditions for "Conventional Combustor" and "Extended-Length, Premix/Prevaporization Combustor Liner".

with the specified restraints even if it were redesigned to change the airflow split.

Using the emission performance trade-off data, as presented in Figure 209 , an assessment of the potential emission reduction was calculated. This calculation was made by equating the NO_x from the "Conventional Liner" and the "Premix/Prevaporization Liner." As shown in Figure 209, this occurs at a fuel/air ratio of approximately 0.0178 in the "Premix/Prevaporization Liner." The corresponding C_xH_y and CO emissions would then be 16.7 and 250 ppm respectively for the "Premix/Prevaporization." These emissions were then used to calculate the emission index for cycle point 5.

The assessment shows that the "Premix/Prevaporization Liner" is 42% better in emission performance than the "Conventional Liner." However, the "Extended-Length Liner" (which was approximately the same length as the "Premix/Prevaporization Liner"), demonstrated lower emissions than the "Premix/Prevaporization Liner." The only change made to the "Conventional Liner" to obtain the "Extended-Length Liner" was to add a 6 inch cylindrical section upstream of the dilution holes. Many more extensive changes are necessary to obtain a "Premix/Prevaporization Liner", thus increasing the development and application risks.

PRECHAMBER COMBUSTOR

One of the low-emission combustor concepts selected during the Task 3 experimental studies was the "Extended-Length, Prechamber Combustor Liner." The concept was based upon a fuel prevaporization approach investigated by Hussmann and Maybach[33] in which recirculated combustion gases vaporized the fuel from the surface of a fuel film. The vaporized fuel was then mixed with inlet air and combustion gases prior to combustion. A combustor based upon this fuel vaporization concept was designed, fabricated, and previously tested in a DDA, GMC gas turbine engine program. The combustor was loaned to this program to evaluate its potential emission performance for nonregenerative, gas turbine engine combustors. The combustor used a ring of tangential fuel jets which spread a thin film of fuel on the inside of a precombustion chamber or prechamber. The swirl air passing through the prechamber mixed with a portion of the hot combustion gases, which were transferred upstream in the swirl vortex. This high-velocity, elevated-temperature swirl vaporized the fuel at the gas-liquid interface along the fuel film. The vaporized fuel-air mixture then expanded out into a large-diameter reaction zone, in which the recirculation was stabilized by the swirl from the prechamber. The combination of prevaporized/premixed fuel coupled with a strong primary-zone recirculation from the prechamber swirl produced a uniform reaction temperature (no hot spots) in a small volume (low residence time), which kept the NO_x low. Prevaporizing the

fuel without cracking the distillate reduced the particulates. The extended length added between the reaction zone and the dilution holes provided longer residence times at intermediate temperatures for consuming the CO, C_xH_y and carbon emissions.

The modifications made to the conventional liner to obtain an "Extended-Length, Prechamber Liner" as shown in Figure 210 were:

- Replace the portion of the conventional T63 combustor liner upstream of the dilution zone cooling annulus with all new hardware. The principal components include:
  - Primary air radial swirler.
  - Wall fuel-film injection system.
  - Wall fuel-film vaporizer tube.
  - Vaporizer tube centerbody.
  - Constant-diameter reaction zone.
  - Convection cooling shell over the reaction zone.
- Replace the dilution and trim holes with a single set of dilution holes 2.10 inches from the end of the liner.
- The total length was 15.56 inches compared to 9.56 inches for the conventional T63 liner.

The airflow distributions for the "Extended-Length, Prechamber Combustor Liner" are itemized below for the two versions tested. The initial design flowed maximum inlet air through the swirler. The first modification (Mod. "A") used a larger diameter centerbody which restricted the swirler air and enriched the prechamber and thus the reaction zone.

	Initial Design	Reduced Primary Airflow
Prechamber Swirler	27.2%	17.0%
Reaction-Zone Holes	6.9%	7.8%
Cooling Step	25.1%	28.7%
Dilution-Zone Holes	40.8%	46.5%
	100.0%	100.0%

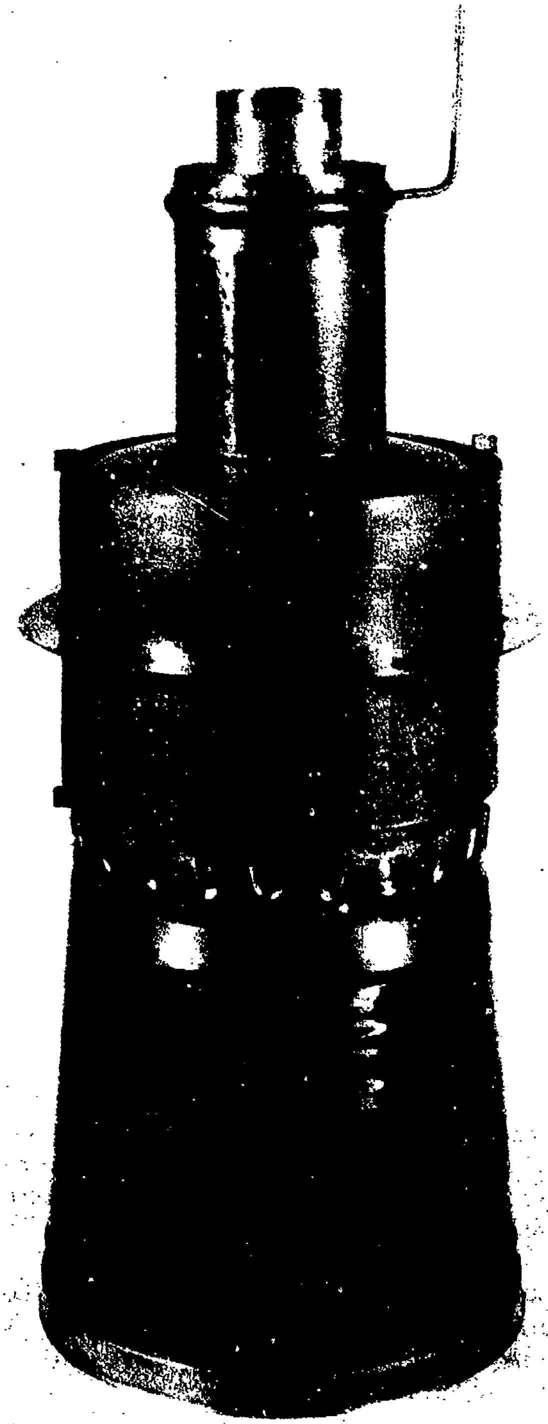


Figure 210. Preliminary Low-Emission, Extended-Length, Prechamber Combustor Liner.

Using the above-calculated flow splits, the reaction-zone throughput equivalence ratios at T63 maximum power were 1.08 for the initial design and 1.72 for the reduced primary airflow design. These equivalence ratios compare to 0.77 equivalence ratio for the conventional T63-A-5A combustor liner at maximum power conditions. A comparison of the "Prechamber Liner" with the baseline combustor is shown in Figure 211, and a photograph of the "Prechamber Liner" tested is shown in Figure 210.

The "Extended-Length, Prechamber Combustor Liner was tested at the conditions presented in Table IV. The tests were conducted at steady-state conditions, in the DDA Combustion Research Laboratory, using JP-4 fuel.

The emission, pressure-loss, and temperature-profile results for the two "Prechamber" liners are summarized and compared with the "Conventional T63-A-5A Liner" and the "Extended-Length Liner" in Tables LXX and LXXI. As shown in the tables, the initial "Prechamber Liner" would not sustain combustion at T63 idle conditions, and no data was obtained at maximum power due to the failure of the centerbody. The richer primary-zone "Prechamber Liner" suffered a fuel line failure at maximum power conditions which terminated the test with no more data being taken. The richer reaction zone and resultingly higher temperature coupled with the high differential pressure across the liner to collapse the reaction zone dome and then to fracture the fuel supply tube weld at the fuel manifold. The emission data obtained from the two tests are plotted in Figures 212 through 215. Comparison of these data shows the following results:

- Carbon monoxide emissions, shown in Figure 212, were considerably reduced by both "Prechamber Liners." Concentrations at 40% and 55% power were even below the CO concentrations of the "Extended-Length Liner."

- Hydrocarbon emissions in Figure 213 exhibited a trend similar to the CO emissions. From a relatively high concentration at the lowest performance condition, concentrations immediately reduced to values below 5 ppm.

- The "Prechamber Liners" produced very low levels of NO_x at all operating conditions. As shown in Figure 214, conventional T63 liner idle NO_x concentrations were not reached until 40% or 55% power conditions.

- The CO vs NO_x data show that the "Prechamber Liners" provided a significant technology improvement in the reduction of both CO and NO_x at several operating points.

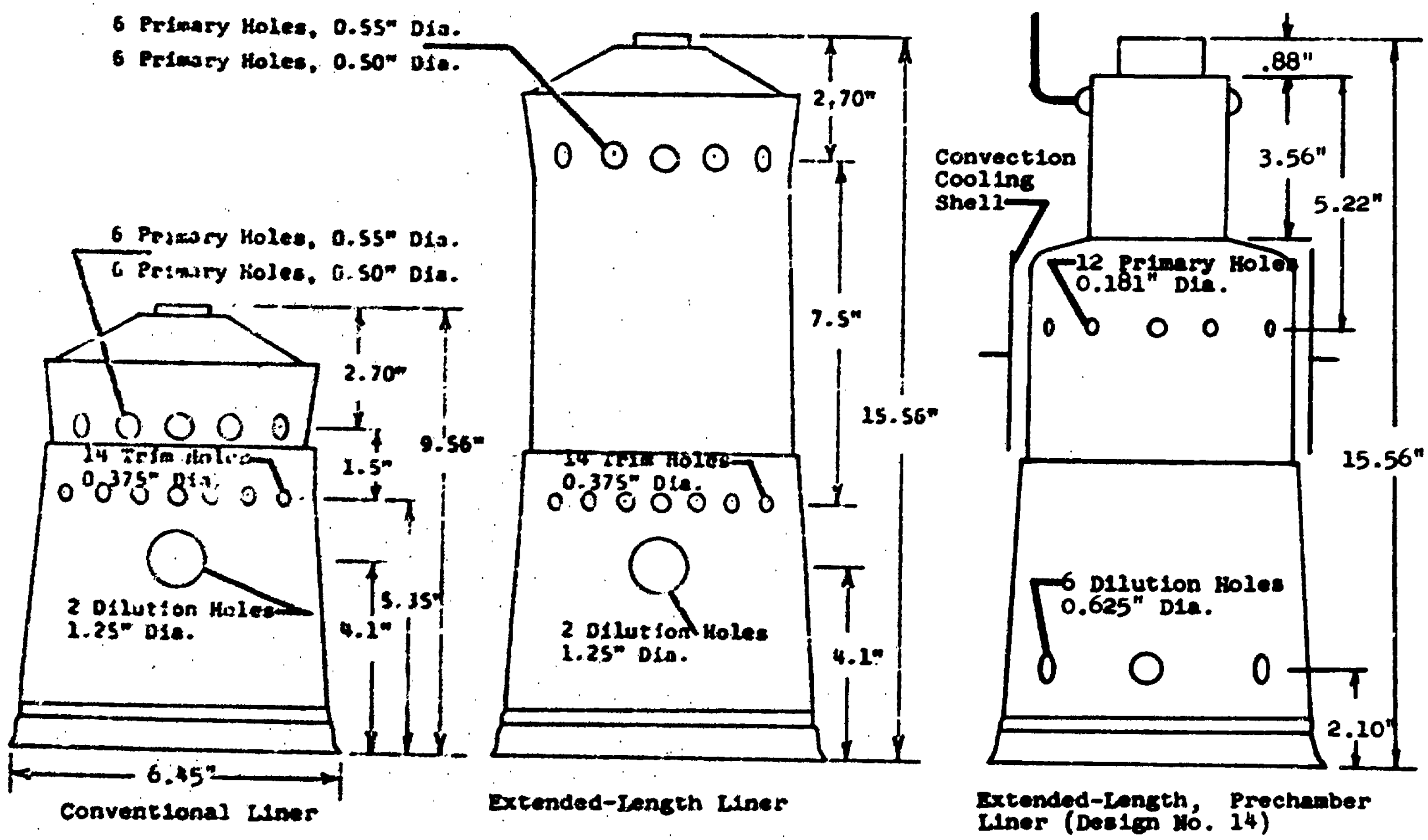


Figure 211. Hole Pattern and Size Comparison of Liners.

TABLE LXX. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL COMBUSTOR, (2) EXTENDED-LENGTH COMBUSTOR, AND (3) EXTENDED-LENGTH, PRECHAMBER COMBUSTOR

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended Length, Prechamber Liner	LEAN BLOWOUT					FAILED CENTERBODY
A. Emissions						
CO, (ppm)		491.2	127.5	49.7	34.9	
H/C, (ppm)		42.0	4.2	.2	1.3	
NO_x, (On-Line, NDIR & NDUV) (ppm)		8.0	12.0	17.0	38.5	
NO_x, (Saltzman) (ppm)		4.28	9.12	19.1	44.9	
Smoke Number		0.0	0.0	0.0	0.0	
B. Pressure Loss (%)		22.97	22.84	23.13	21.57	
C. Temp. Profile (T_{max}/T_{avg})		1.113	1.109	1.119	1.092	

TABLE LXXI. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) EXTENDED-LENGTH COMBUSTOR, (2) EXTENDED-LENGTH, PRECHAMBER COMBUSTOR, AND (3) EXTENDED-LENGTH, PRECHAMBER COMBUSTOR WITH RICH PRIMARY ZONE

	Cycle Point					
	1	6	5	4	3	2
I. Extended Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})						
II. Extended-Length Prechamber Liner	LEAN BLOWOUT					CENTRIFUGAL FAILURE
A. Emissions						
CO, (ppm)		491.2	127.5	49.7	34.9	
H/C, (ppm)		42.0	4.2	.2	1.3	
NO_x, (On-Line, NDIR & NDUV) (ppm)		8.0	12.0	17.0	38.5	
NO_x, (Saltzman) (ppm)		4.28	9.12	19.1	44.9	
Smoke Number		0.0	0.0	0.0	0.0	
B. Pressure Loss (%)		22.97	22.84	23.13	21.57	
C. Temp. Profile (T_{max}/T_{avg})		1.113	1.109	1.119	1.092	
III. Extended-Length, Prechamber Liner with Richer Primary Zone						FUEL LINE FAILURE
A. Emissions						
CO, (ppm)	525.3	65.2	34.9	40.1	52.4	
H/C, (ppm)	70.0	1.8	.2	.8	.1	
NO_x, (On-Line, NDIR & NDUV) (ppm)	5.5	9.5	18.0	28.0	49.5	
NO_x, (Saltzman) (ppm)	2.76	5.21	9.98	26.2	--	
Smoke Number	0.0	0.0	0.0	0.0	0.0	
B. Pressure Loss (%)	22.28	22.58	24.36	23.85	24.25	
C. Temp. Profile (T_{max}/T_{avg})	1.090	1.108	1.085	1.193	1.180	

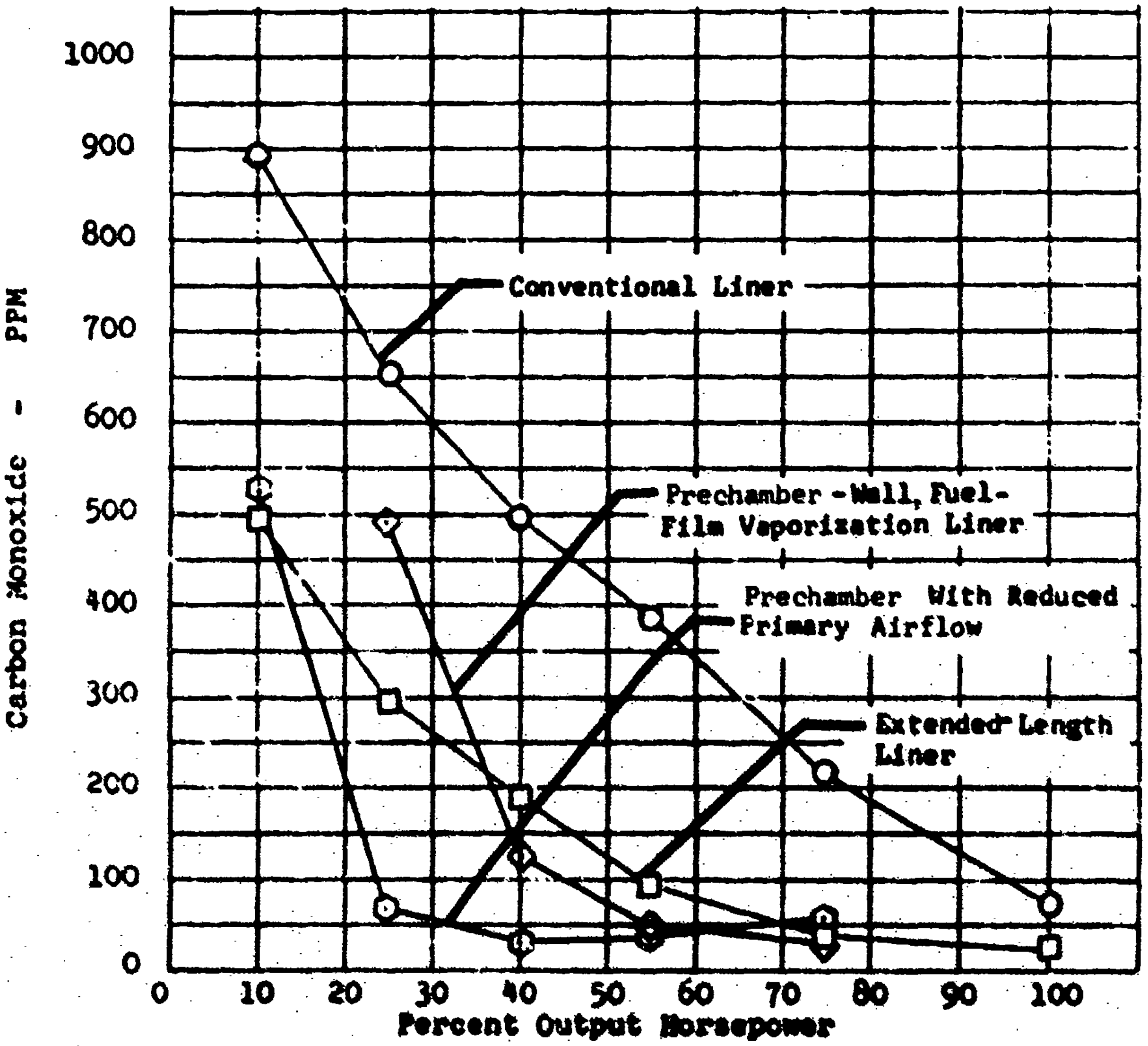


Figure 212. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Prechamber-Wall, Fuel-Film Vaporization Combustor and T63 Baseline Combustors.

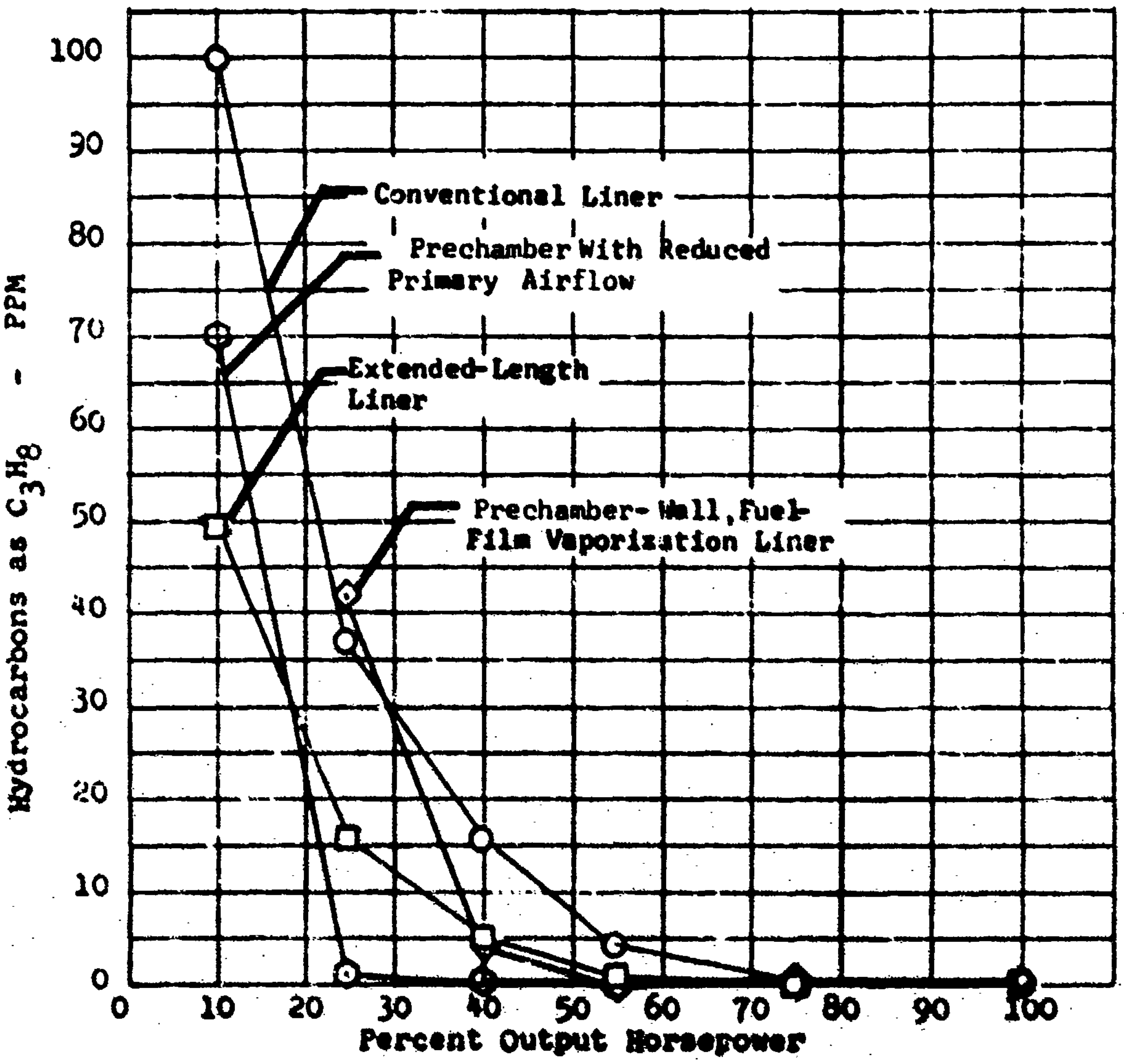


Figure 213. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Prechamber-Wall, Fuel-Film Vaporization Combustor and T63 Baseline Combustors.

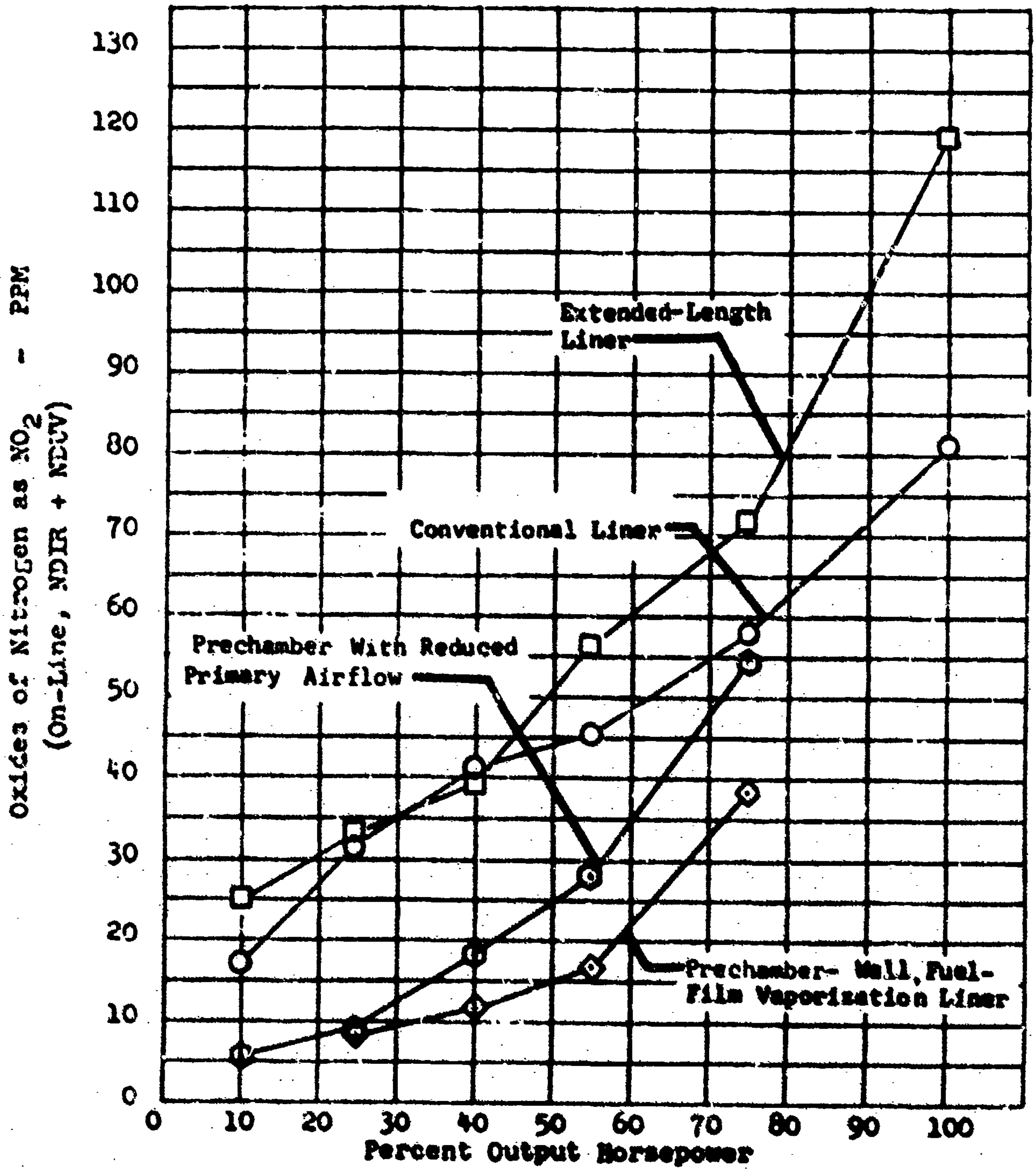


Figure 214. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber-Wall, Fuel-Film Vaporization Combustor and T63 Baseline Combustors.

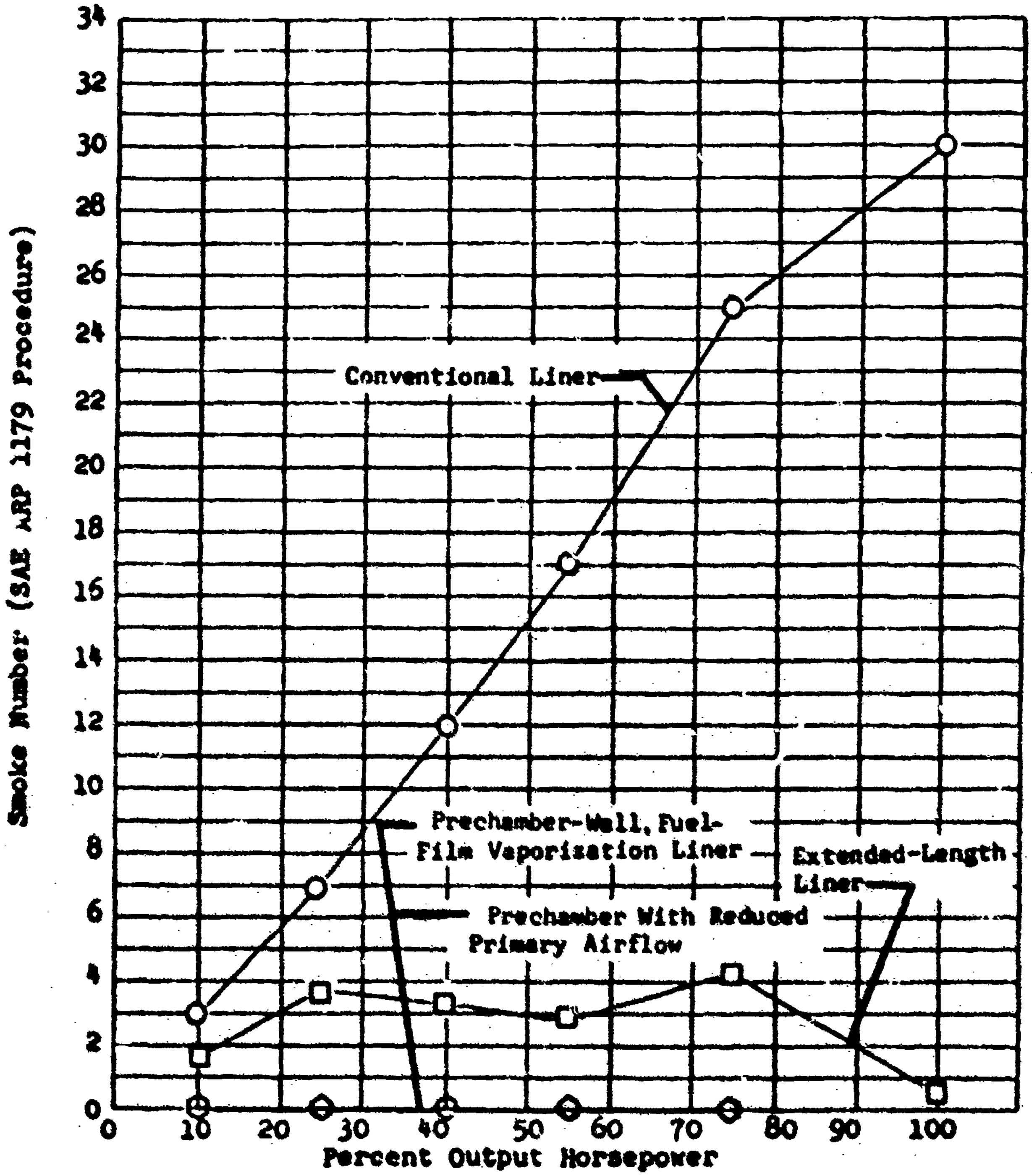


Figure 215. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Prechamber-Wall, Fuel-Film Vaporization Combustor and T63 Baseline Combustors.

- The most significant data are the smoke data given in Figure 215. As shown by these curves, smoke was <u>zero</u> for all operating conditions at which the combustors were operated.

The temperature profiles (T_{max}/T_{avg}) from the "Extended-Length, Prechamber Combustor Liners" were quite good for most of the operating conditions, as shown in Figure 216. The initial design "Prechamber Liner" produced a very consistent profile. A significant fact to remember, however, is the excessively high pressure loss experienced by these combustors since they were operating at conditions considerably beyond their design points.

The measured pressure losses of the "Extended-Length, Prechamber Combustor Liners" were nominally 22.63% for the initial design and 23.46% for the richer primary-zone design. These excessive pressure losses make the "Prechamber Combustor Liners" impractical as designed. Resizing the swirler and all primary and dilution holes for lower pressure loss is required to give this combustor concept application as a gas turbine combustor.

Using the emission data presented in the Tables LXX and LXXI and Figures 212 through 215, the emissions index (EI) values for the selected LOH duty cycle were calculated. The total EI for the "Extended-Length, Prechamber Combustor Liners" required extrapolation of the actual data to those conditions for which emissions data were not obtained. For the initial design "Prechamber Liner", this required extrapolation to both idle and maximum power T63 conditions. The idle CO and C_xH_y concentrations used were equal to conventional liner concentrations for CO and above conventional liner concentrations for C_xH_y. The NO_x level was maintained at approximately the 25% power concentration. At maximum power, CO, and C_xH_y were maintained at concentrations near those at 75% power, and NO_x was extrapolated to a concentration nearly double the 75% power NO_x level. For the richer primary-zone version, the extrapolations for maximum power resulted in a CO concentration equal to that of the conventional liner, and C_xH_y was held at the 75% power level. The NO_x was extrapolated to a concentration above the conventional NO_x level at maximum power, even though the NO_x concentration of the prechamber was below the conventional at 75% power. Smoke/particulates for all extrapolated points were assumed to be zero.

Using the actual and extrapolated emission data resulted in a calculated total EI of 13.517 lb/1000 lb fuel for the initial "Prechamber Liner" and 10.641 lb/1000 lb fuel for the richer primary zone version (Mod. "A"). Therefore, as shown in Table XLVI, the total emissions from the two "Extended-Length, Prechamber Combustor Liner" were 41% and 32% of the emissions from the "Conventional T63 Liner" and met this portion of the contract objectives. As also shown in Table XLVI, each constituent emission was reduced, and no constituent increased above the "Conventional T63 Liner" emission levels.

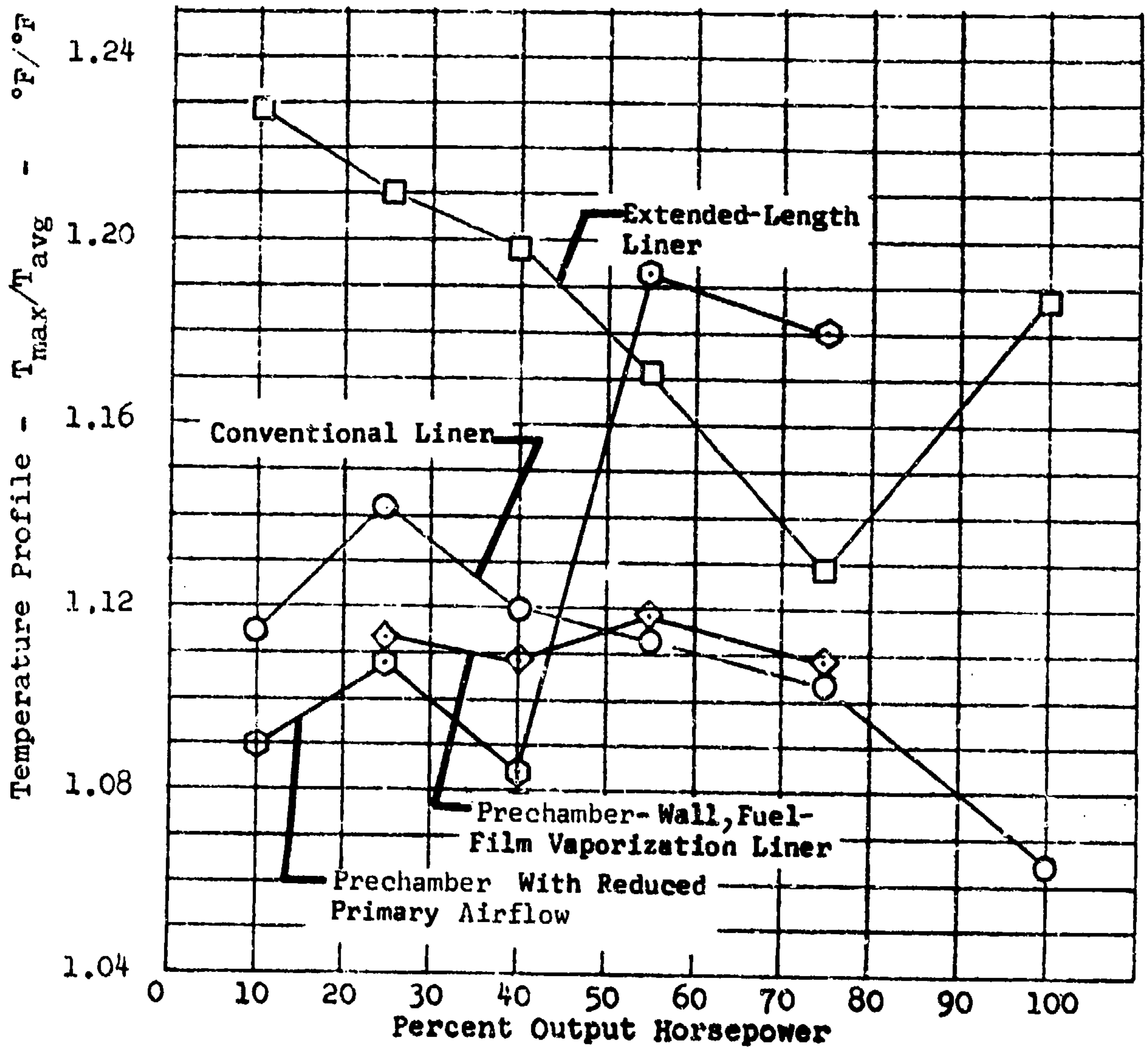


Figure 216. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Prechamber-Wall, Fuel-Film Vaporization Combustor and T63 Baseline Combustors.

Visual examination of the combustor liners after the tests revealed that damage had occurred to each. In the initial design liner, the high pressure differential at maximum power fractured the tack welds holding the centerbody, causing it to be carried downstream and lodge against the exhaust instrumentation section of the test rig. The richer primary-zone configuration experienced a collapsing of the reaction-zone dome.

The movement of the vaporization tube assembly aft was restrained by only the fuel line, which ultimately fractured at the fuel-line fuel-manifold weld. Raw fuel was carried through the swirler (two blades were destroyed) and onto the larger centerbody. The burning fuel melted the centerbody, destroying it, and melted a sizable hole through the vaporizer tube. These failures terminated any further testing of these liners.

The "Extended-Length Prechamber, Combustor Liners" gave reductions of 59% and 68% compared to the "Conventional T63-A-5A Combustor Liner." Therefore, the "50% minimum reduction of total emissions" objective for the contract was met. The second objective, "no constituent emission increase", was also satisfied. Significant reductions in all individual emissions were obtained. The most outstanding feature of this combustor concept was the elimination of smoke (particulates) at all operating conditions tested. Temperature profile was also very good, especially in the initial design "Prechamber Liner."

The worst feature of the "Extended-Length, Prechamber Combustor Liners" was the exceptionally high pressure loss experienced when the combustors were operated at the T63 combustor conditions. These combustors were designed for a much lower airflow and inlet pressure, but they were tested at T63 conditions because of their availability from another combustor program.

Because of the high reduction in both total and individual emissions, it was recommended that the "Extended-Length, Prechamber Combustor Liner" concept be included as one of the final concepts to accomplish the contract objectives.

OPTIMUM PRIMARY COMBUSTOR

One of the low emission concepts selected during the Task 3 experimental studies was the "Extended-Length, Optimum Primary-Holes Combustor Liner". The concept is to replace the existing twelve-hole primary hole pattern with a symmetric six-hole pattern providing the same primary-zone air addition. It was anticipated that a fewer number of larger jets of air would increase the primary zone mixing and recirculation, thus reducing emissions by attaining

more uniform combustion. The "Extended-Length, Optimum Primary-Holes Combustor Liner" incorporated the following features to reduce emissions:

- Six equally spaced primary air holes to evaluate the effect of the primary air hole pattern on combustor performance and emissions.

- Extended length to allow additional residence time to react the CO, C_xH_y, and particulates. Previous reaction kinetics studies and experiments in Task 2 had shown that the extended length would significantly reduce CO and C_xH_y emissions with a small increase in NO_x emissions.

The modifications made to the conventional liner to obtain an "Extended-Length, Optimum Primary-Holes Liner" as shown in Figure 217 were:

1. Add constant-diameter, 6-inch-long section between the primary holes and the film coolant step.

2. Close original row of primary holes.

3. Add new row of six 0.750-inch-diameter primary holes in the same axial location as on the conventional T63 liner.

The hole patterns and sizes for the "Extended-Length, Optimum Primary-Holes Liner," and "Conventional Liner," are shown in Figure 218. Both liners had the same airflow area split as, tabulated below:

Dome Holes	11.8%
First Cooling Step	11.2%
Primary Holes	26.3%
Second Cooling Step	11.2%
Trim Holes	15.2%
Dilution Holes	24.2%
	99.9%

With the above-calculated flow splits, the primary-zone equivalence ratio at T63 maximum power is 0.77.

The "Extended-Length, Optimum Primary-Holes Liner" was tested in

Figure 217. Preliminary Low-Emission, Extended-Length, "Optimum" Primary-Holes Combustor Liner.

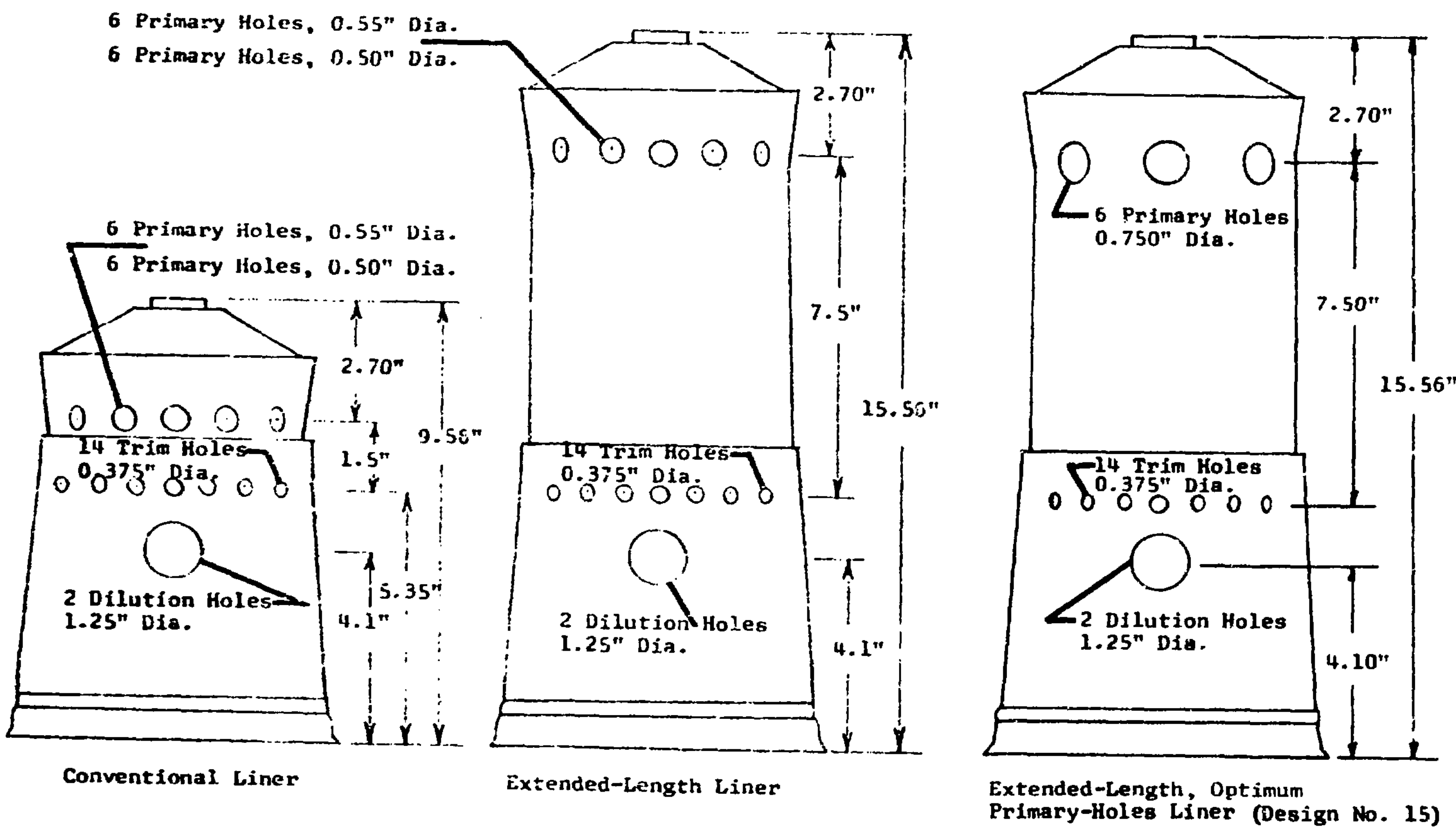


Figure 218. Hole Pattern and Size Comparison of Liners.

the T63 combustor rig at the nonregenerative T63 combustor conditions tabulated in Table IV. The tests were conducted at steady-state conditions using JP-4 fuel. The emission, pressure-loss, and temperature-profile results are summarized and compared with the "Conventional T63-A-5A Liner" and the "Extended-Length Liner" in Table LXXII. All three liners were tested with the conventional T63 pressure atomizing fuel injector and JP-4 fuel.

Carbon monoxide, hydrocarbon, oxides of nitrogen,and smoke emission results for the "Extended-Length, Optimum Primary-Holes Liner," the "Extended-Length Liner",and "Conventional Liner" are plotted in Figures 219 through 222. Comparison of the emission data in these figures shows:

- The CO emissions shown in Figure 219 were significantly below the "Conventional T63-A-5A Liner" concentrations and slightly below the "Extended-Length Liner" levels.

- A significant improvement was made by the "Extended-Length, Optimum Primary-Holes Liner" in further reducing the hydrocarbon emissions below the low concentrations already achieved by the "Extended-Length Liner." As seen in Figure 220,the hydrocarbons were more than a factor of three lower than the concentrations from the "Conventional T63-A-5A Liner."

- The NO_x emissions plotted in Figure 221 were higher than the concentrations for the "Conventional T63-A-5A Liner," remaining almost equal to the "Extended-Length Liner" at each operating condition.

- The level of smoke/particulates was only half of the level from the "Conventional T63-A-5A Liner," although these emissions increased above those measured from the "Extended-Length Liner."

Using the emission data presented in Table LXXII and Figures 219 through 222, an emission index (EI) for the selected LOH duty cycle was calculated. The total duty cycle EI for the "Extended-Length, Optimum Primary-Holes Combustor Liner" was 14.459 lb/1000 lb fuel. This compares with 32.946 lb/1000 lb fuel for the "Conventional Liner" and 15.718 lb/1000 lb fuel for the "Extended-Length Liner." Therefore, as shown in Table XLVI, the total emissions from the "Extended-Length, Optimum Primary-Holes Combustor Liner" were 44% of the emissions from the "Conventional Liner." Compared to the "Extended-Length Liner," the effect of the six-hole primary pattern was to decrease the total emissions from 48% of baseline to 44%, which is a relative decrease of 8%.

The temperature profile (T_{max}/T_{avg}) from the "Extended-Length, Optimum Primary-Holes Combustor Liner" was worse than from the

TABLE LXXII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL COMBUSTOR, (2) EXTENDED-LENGTH COMBUSTOR, AND (3) EXTENDED-LENGTH, OPTIMUM PRIMARY-ZONE COMBUSTOR

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	79
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	91.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.[illegible]
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended-Length Liner						
A. Emissions						
CO, (ppm)	495	298	185.5	94.0	38.6	22.6
H/C, (ppm)	49.	15.8	5.1	1.0	0.5	0.4
NO_x, (On-Line, NDIR & NDUV) (ppm)	25.0	33.0	39.5	56.5	72.0	119.5
NO_x, (On-Line, CL) (ppm)	19.0	26.5	35.0	47.0	68.0	113.3
NO_x, (Saltzman) (ppm)	24.8	38.3	41.0	56.0	79.7	123.9
Smoke Number	1.72	3.76	3.28	2.80	4.20	0.59
B. Pressure Loss (%)	5.10	4.61	5.09	4.91	4.74	4.59
C. Temp. Profile (T_{max}/T_{avg})	1.229	1.210	1.198	1.171	1.129	1.188
III. Extended-Length, Optimum Primary-Zone Liner.						
A. Emissions						
CO, (ppm)	482.7	278.6	150.8	75.6	33.3	16.7
H/C, (ppm)	33.0	9.0	1.7	.4	.4	.0
NO_x, (On-Line, NDIR & NDUV) (ppm)	24.5	26.0	40.5	57.0	75.5	118.5
NO_x, (Saltzman) (ppm)	22.6	33.7	45.6	--	--	--
Smoke Number	0.00	0.00	2.60	5.51	13.06	14.03
B. Pressure Loss (%)	5.05	5.28	5.19	4.83	4.76	4.48
C. Temp. Profile (T_{max}/T_{avg})	1.192	1.177	1.151	1.181	1.193	1.155

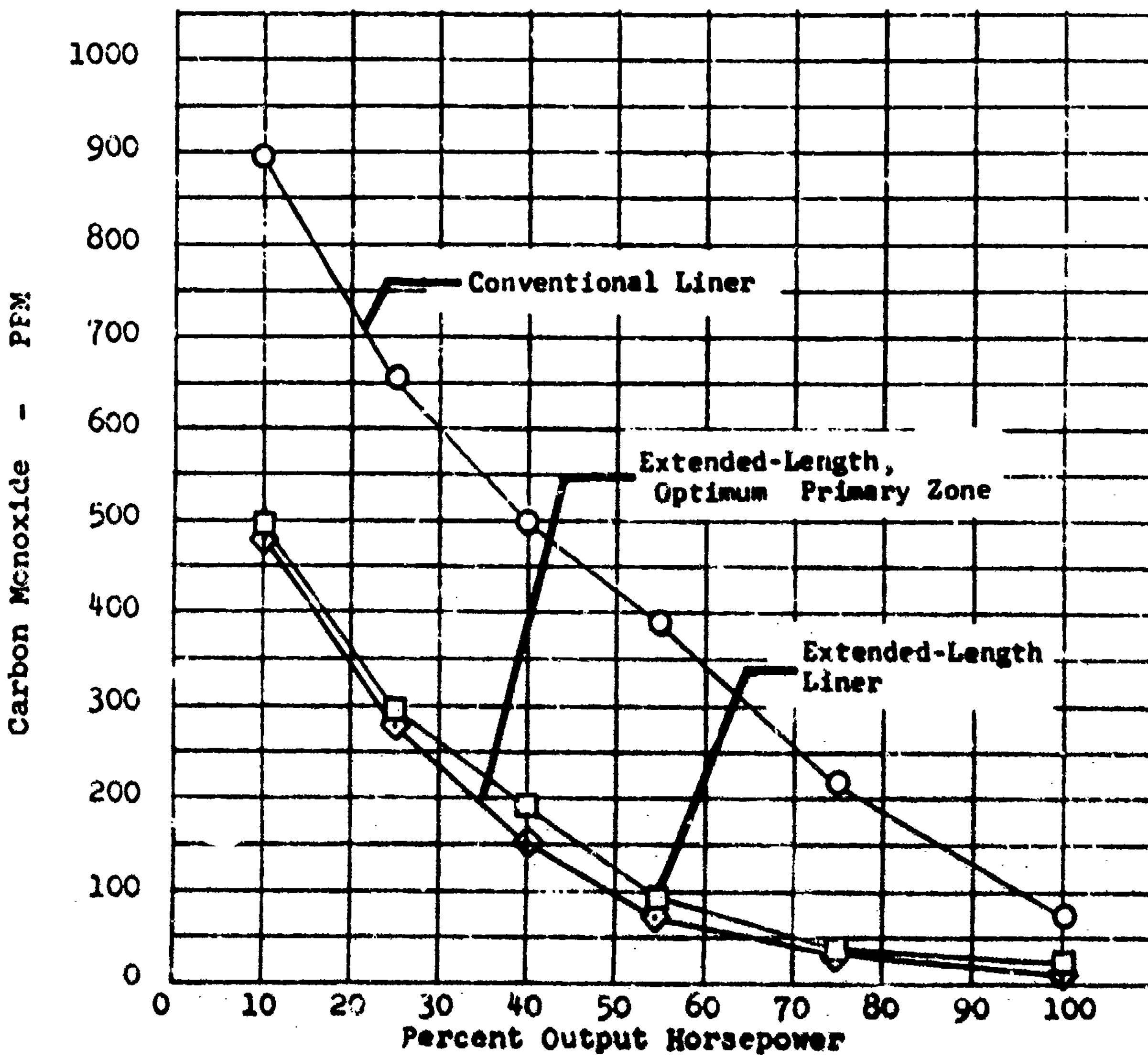


Figure 219. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Optimum Primary-Air Hole Pattern and T63 Baseline Combustors.

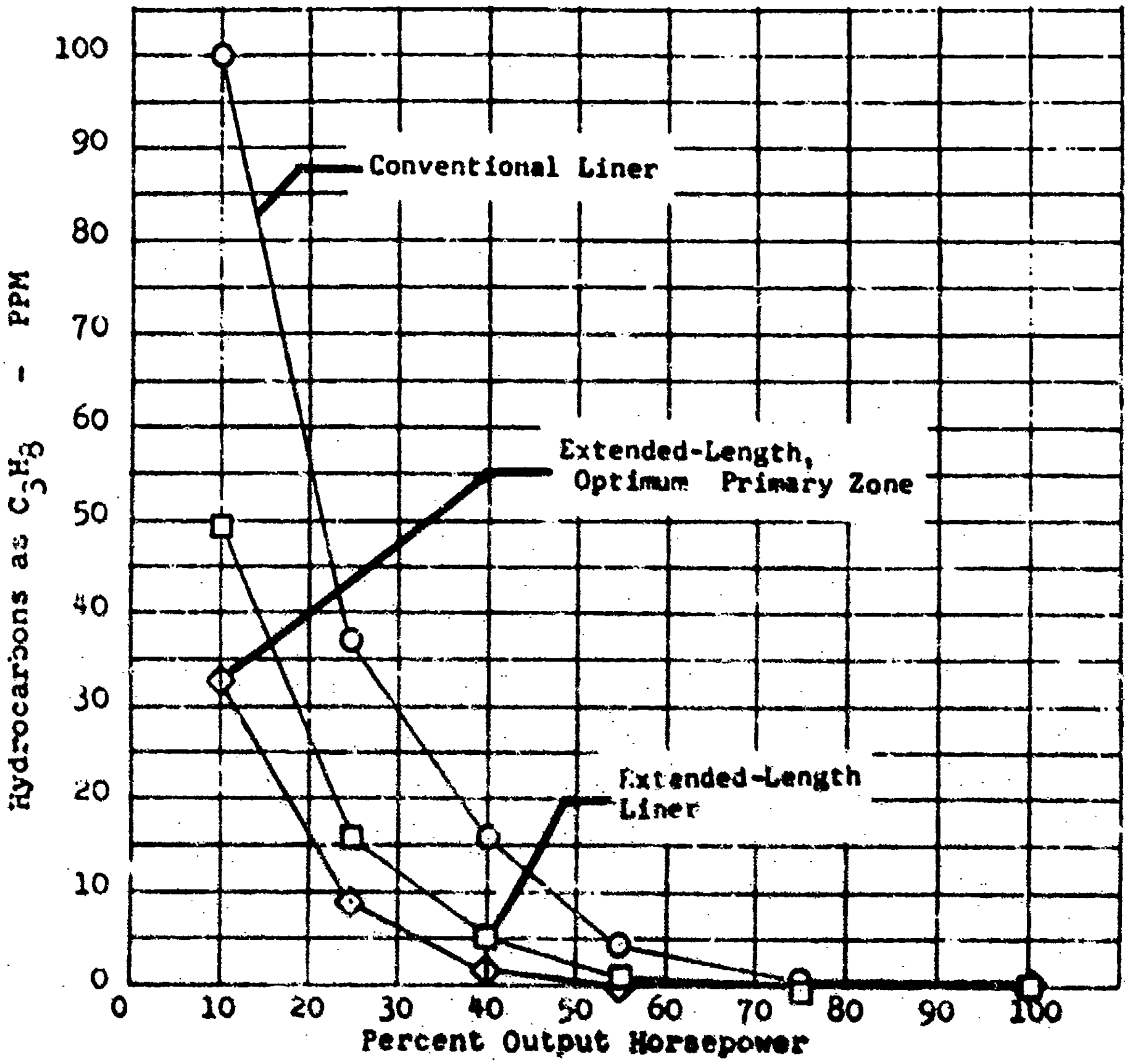


Figure 220. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Optimum Primary-Air Hole Pattern and T63 Baseline Combustors.

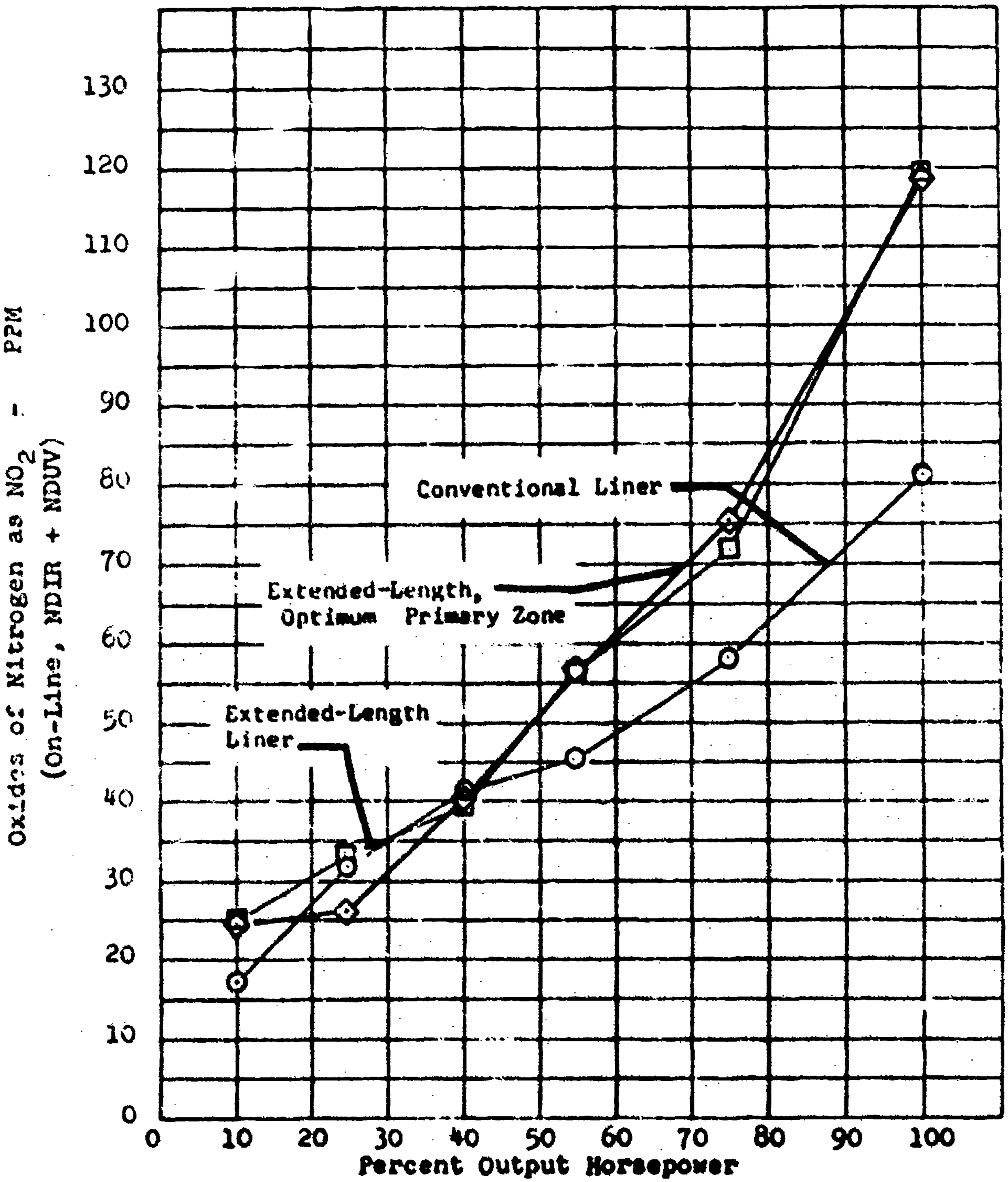


Figure 221. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Optimum Primary-Air Hole Pattern-Design #15 and T63 Baseline Combustors.

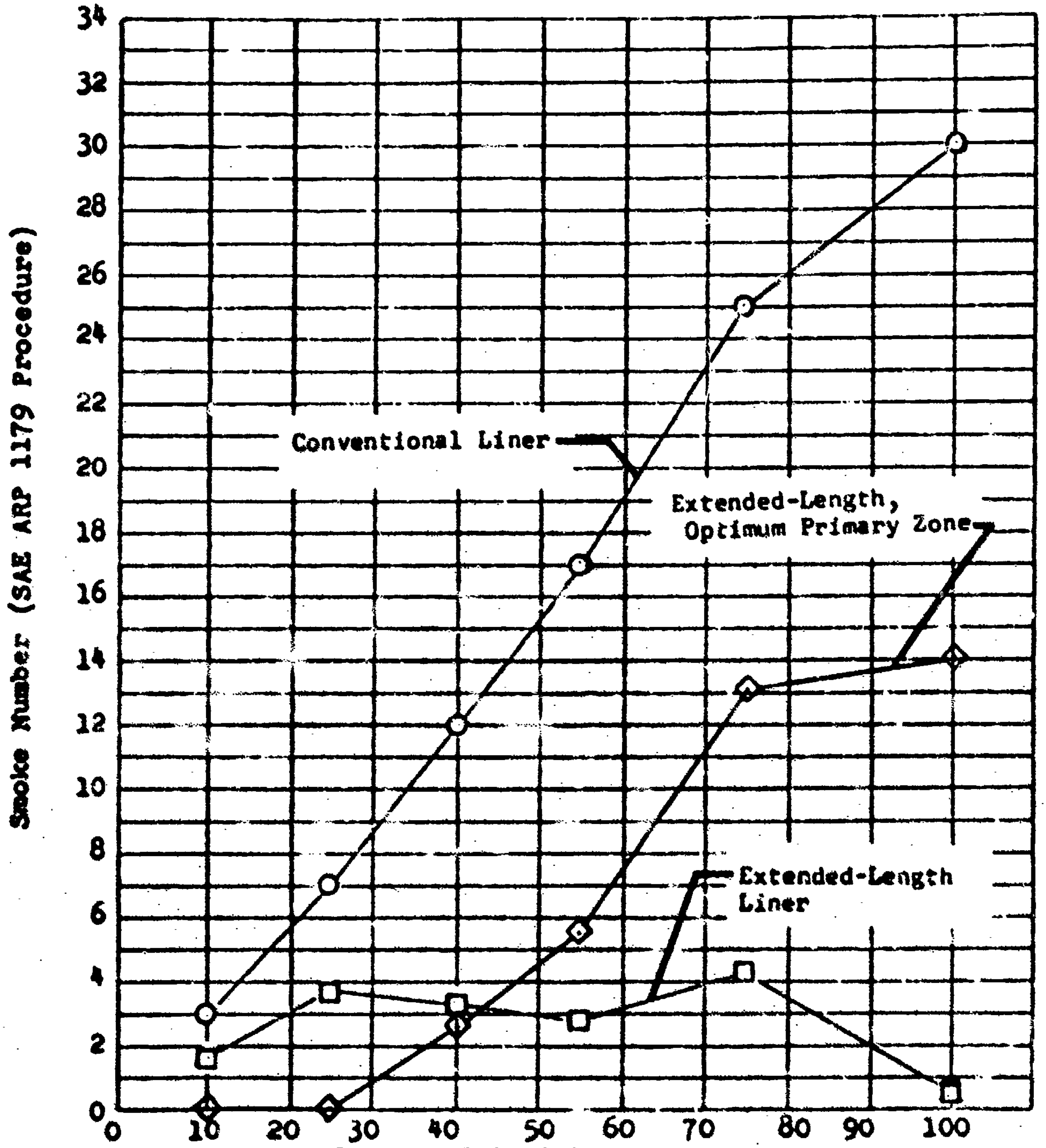


Figure 222. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Optimum Primary-Air Hole Pattern-Design #15 and T63 Baseline Combustors.

"Conventional Liner" at all power levels; see Figure 223. It had slightly better temperature profile than the "Extended-Length Liner" for all operating conditions except 55% and 75% power.

The average measured pressure loss of the "Extended-Length, Optimum Primary-Holes Combustor Liner" was 4.93% for the six data points. This compares to average pressure losses of 4.44% for the "Conventional Liner" and 4.84% for the "Extended-Length Liner."

Visual examinations of the combustor liner after the test did not reveal any apparent damage.

The "Extended-Length, Optimum Primary-Holes Combustor Liner" gave a 56% reduction in total emissions compared to the "Conventional T63-A-5A Combustor Liner." Compared to the "Extended-Length Combustor Liner" the total emissions decreased 8%. Thus, when also considering the emission results from the "Extended-Length Combustor Liner", changing the number of primary air holes from twelve to six may not detrimentally affect the combustor's performance or emission production. The six-hole pattern effected lower C_xH_y, higher particulates, and no significant change in CO and NO_x.

The six-hole primary-air injection approach did not significantly reduce the total emissions below the levels attained by the conventional twelve-hole approach. It is therefore recommended that since the six-hole primary air has almost no effect on CO and NO_x, which are the major contributors to the total emissions in the T63 combustor, the change from twelve to six primary holes not to be incorporated into the final design.

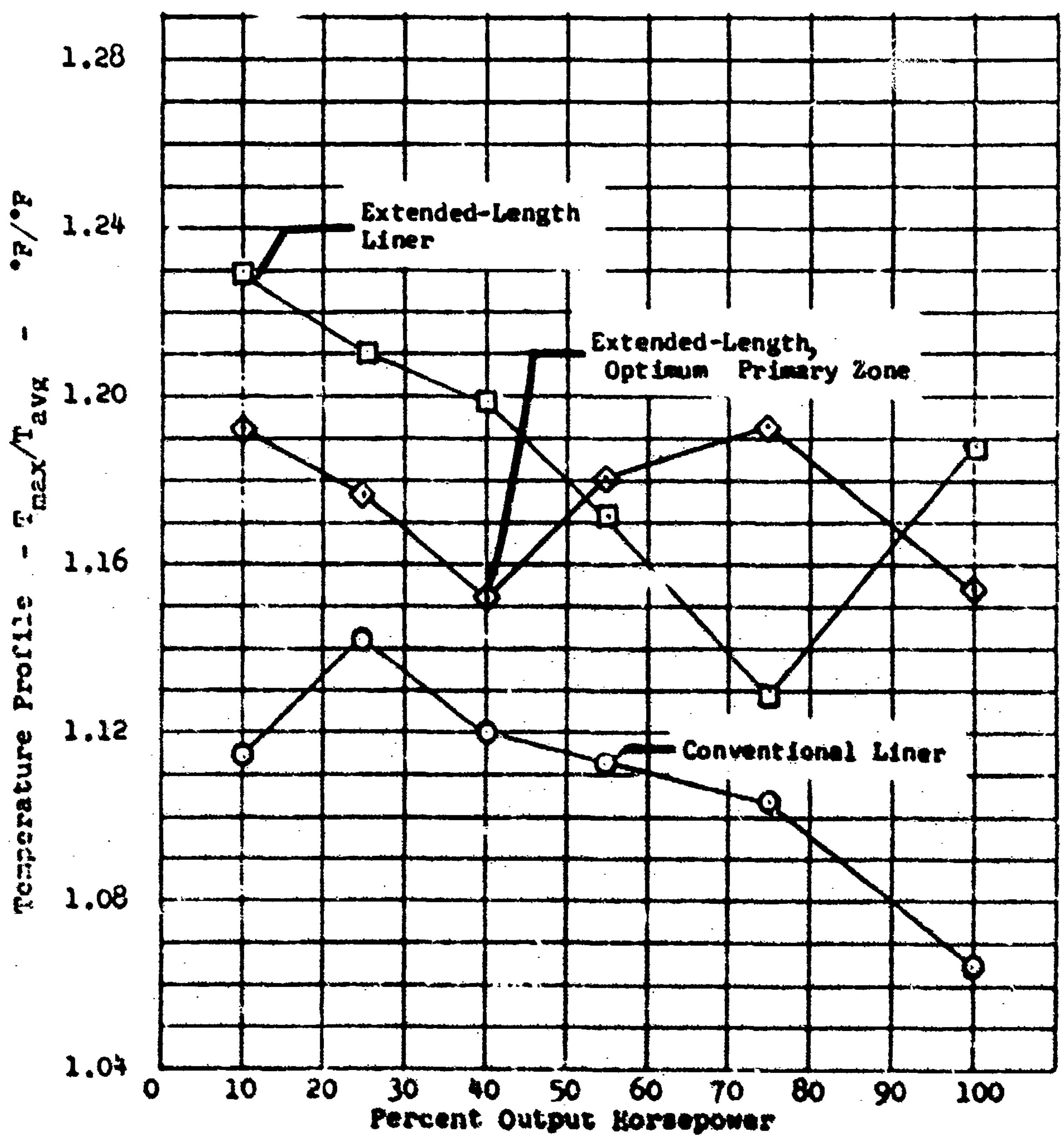


Figure 223. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Optimum Primary-Air Hole Pattern - Design #15 and T63 Baseline Combustors.

APPENDIX III
DESIGN AND EXPERIMENTAL RESULTS OF THE FINAL, PRECHAMBER, LOW-EMISSION COMBUSTORS

Two final combustor configurations were selected from the test results of the seventeen preliminary combustors evaluated during the first part of Task 3. These two final combustors were identified as the "Final Prechamber Combustor Liner" and the "Final Modified Conventional Combustor Liner." Reported in this appendix is the "Final Prechamber Combustor Liner."

DESIGN

Two of the preliminary low-emission combustor concepts which showed substantial emission reductions were the "Rich Premix/Swirl Combustor Liner" and the "Prechamber Combustor Liner". Both of these combustors utilized a premix cup with a swirl dome, a sudden expansion into the reaction zone, convection cooling of the reaction zone, extended overall length, and delayed dilution. One fundamental difference between these two preliminary liners was the method of fuel injection. The "Rich Premix/Swirl Combustor" used a conventional T63 pressure atomizing fuel injector, centrally located in the swirler dome of the premix cup. The "Prechamber Combustor" injected the liquid fuel on the inside wall of the premix cup or vaporizer tube and relied upon the high-velocity swirl air to vaporize the fuel off the wall.

Being quite similar in several respects, these two premix cup preliminary combustors were combined into a single final design combustor called the "Final Prechamber Combustor Liner". As can be seen in the photograph in Figure 224, both the pressure atomizer and the wall fuel film injection methods were incorporated into the premix cup or vaporizer tube dome end of the liner. The overall length of the Final Prechamber was reduced from the preliminary combustor lengths to be only 3 inches longer than the conventional T63 combustor. This reduction in length was obtained by reducing the combustor length between the reaction-zone row of holes and the dilution row of holes. The reaction-zone liner diameter was increased from 5.30 inches to 6.34 inches to provide more combustion volume and to increase the inlet air velocity between the liner and the outer combustor case to create a convection cooling region along the liner reaction zone. Delayed dilution was retained for consumption of the carbon monoxide, hydrocarbons, and particulates.

A number of minor and major modifications on the "Final Prechamber Combustor" were made in attempts to further reduce emissions and improve combustor performance. These modifications are summarized in Table LXXIII. The first rework of the "Final Prechamber" was to remove 1.50 inches of axial length from the vaporizer tube and to add 1.50 inches downstream of the dilution holes, see Figure 225. It was intended that the reduction in the vaporizer tube length would

Figure 224. Final Low-Emission Prechamber Combustor Liner, Initial Configuration.

TABLE LXXIII. FINAL DESIGN PRECHAMBER COMBUSTORS DESIGN SUMMARY

Design Parameter	Initial Design	Mod. "A"	Mod. "B"	Mod. "C"	Mod. "D"
Hole Sizes (inches)					
Fuel Film Injector (16)	.013	.013	.021*	.021	.021
Reaction Zone (12)	.360	.360	.297*	Closed*	Closed
Dilution Zone (6)	1.344	1.344	1.310*	1.310	1.310
Lengths (inches)					
Overall	12.670	12.670	12.670	12.670	12.670
Vaporizer Tube	4.445	2.945*	4.500*	4.500	4.500
Vaporizer Tube-Reaction Holes	1.500	1.500	1.400*	1.400	1.400
Reaction Holes-Dilution Holes	3.730	3.730	3.730	3.730	3.730
Dilution Holes-Liner End	2.100	3.600*	2.100*	2.100	2.100
Diameters (inches)					
Swirler I.D.	1.670	1.670	2.410*	2.410	2.410
Swirler O.D.	2.960	2.960	3.680*	3.680	3.680
Vaporizer Tube I.D.	3.080	3.080	3.800*	3.800	3.800
Reaction Zone O.D.	6.340	6.340	6.340	6.340	6.340
Dilution Holes I.D.	5.640	5.640	5.640	5.640	5.640
Exhaust O.D.	6.210	6.210	6.210	6.210	6.210
Fuel Injection Mode Tested					
Pressure Atomizer	Yes	Yes	Yes	No	No
Wall Fuel Film	Yes	Yes	Yes	Yes	Yes
Vaporizer Tube Centerbody	No	No	No	No	Yes*

*Indicates change from previous design.

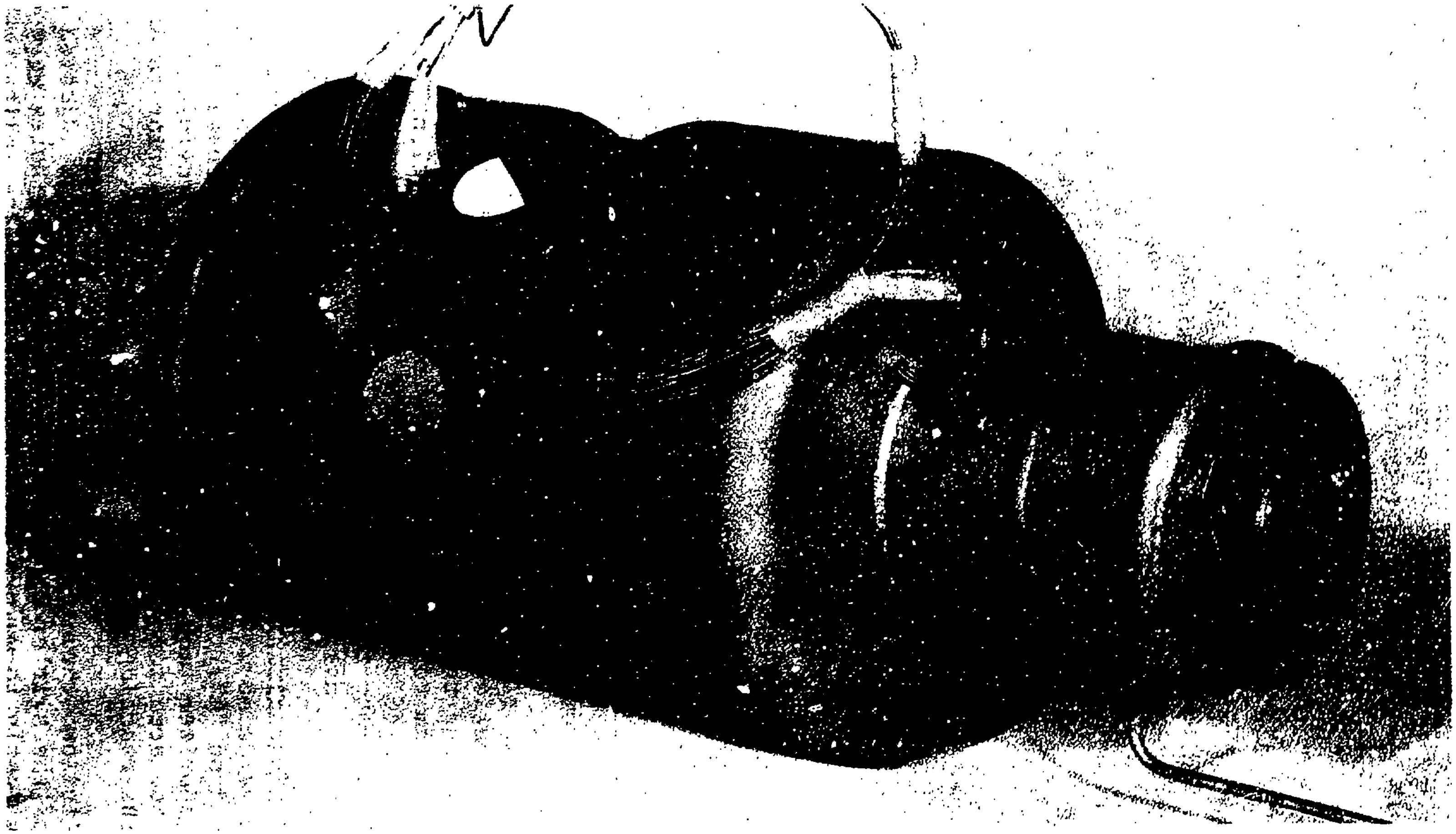


Figure 225. Final Low-Emission Prechamber Combustor Liner, Modification "A".

allow more combustion gases to be pumped up the swirl vortex and be mixed with the swirler air. The increased vaporizer tube recirculation would then raise the air/combustion-gas mixture temperature and provide better fuel vaporization of the wall fuel film. The added length downstream of the dilution zone was to allow additional volume prior to the combustor exit for improvement of the exhaust temperature profile.

Modification "B", as indicated in Table LXXIII, was a complete redesign and refabrication of the swirler/wall fuel film injector/ vaporizer tube section as well as readjustment of the flow splits among the swirler, reaction zone, and dilution zone. External and internal photographs of Modification "B" are presented in Figures 226 and 227. Design changes from the initial design to this design were intended to improve the vaporization and premixing of the fuel and air prior to their expansion into the reaction zone. It was apparent from the Modification "A" test results that the added liner length downstream of the dilution holes did not result in an improved exhaust temperature profile. Uniform combustion in the primary zone generally resulted in a reasonable exhaust temperature profile.

The specific design differences in Modification "B" were the following:

1. The vaporizer tube swirler throughput airflow was increased from 15% to 22.5% of the total flow to provide more swirl air for fuel vaporization. This increase in swirler air and adjustment in the reaction zone hole sizes also reduced the reaction zone equivalence ratio back to unity at takeoff-power combustor operating conditions.

2. The vaporizer tube cross-sectional area to swirler annular area ratio was increased from 1.59 to 1.81 to provide more area for the swirl vortex to bring hot reaction products upstream to the fuel film for fuel vaporization. Both the increased swirler airflow and the larger area ratio produced more fuel vaporization surface area per unit length than was available in the initial "Prechamber Liner".

3. The vaporization tube length-to-diameter ratio was reset to a value about midway between the initial design and Modification "A". These changes collectively increased the vaporizer tube surface area by 25%, thus providing more surface area for fuel vaporization and mixing prior to entering the reaction zone.

4. Airflow through the reaction-zone holes was adjusted to 25% of the swirler airflow. The dilution zone holes were trimmed slightly to maintain the desired liner flow splits.

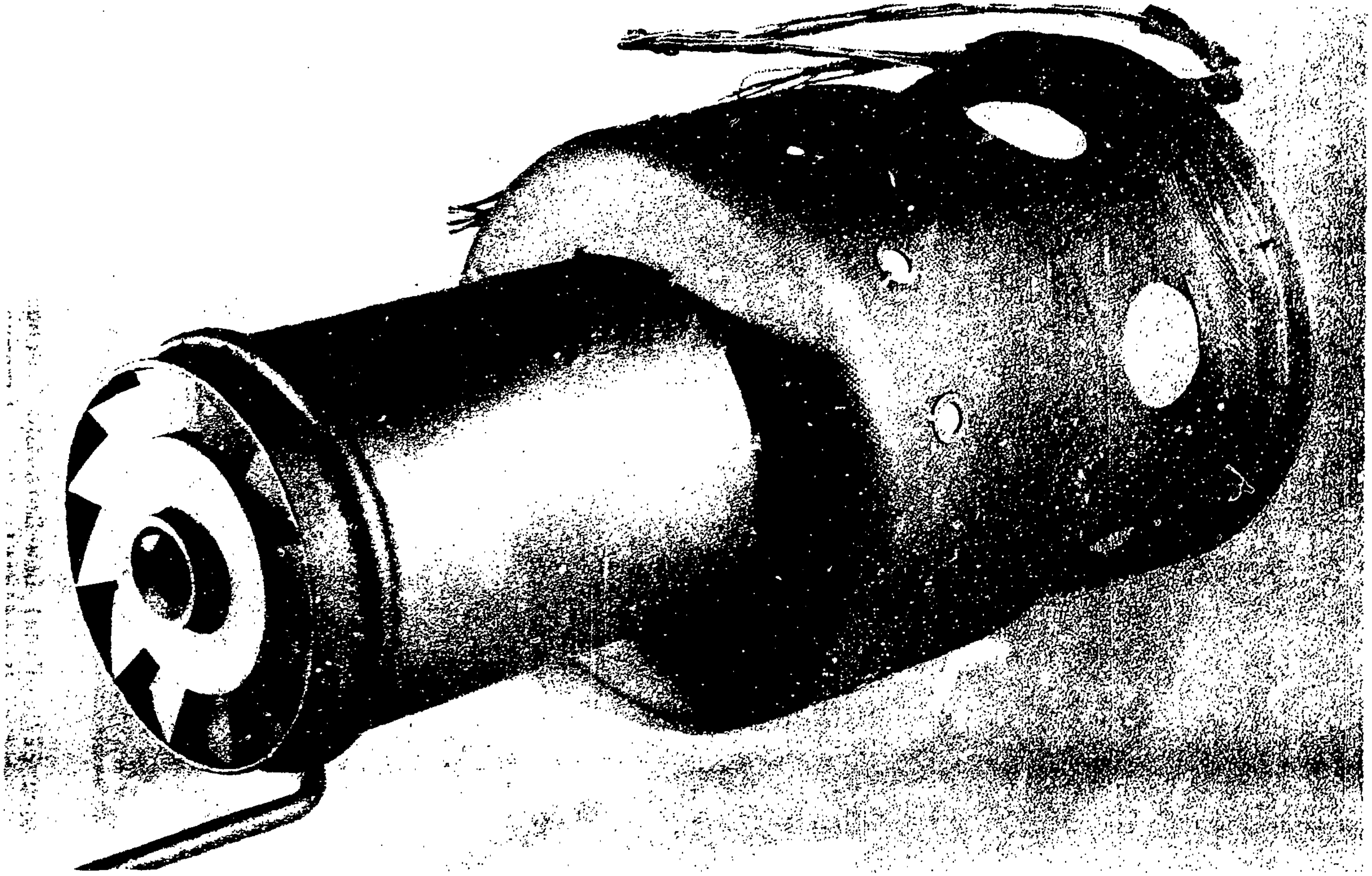


Figure 226. Final Low-Emission Prechamber Combustor Liner, Modification "B", External View.

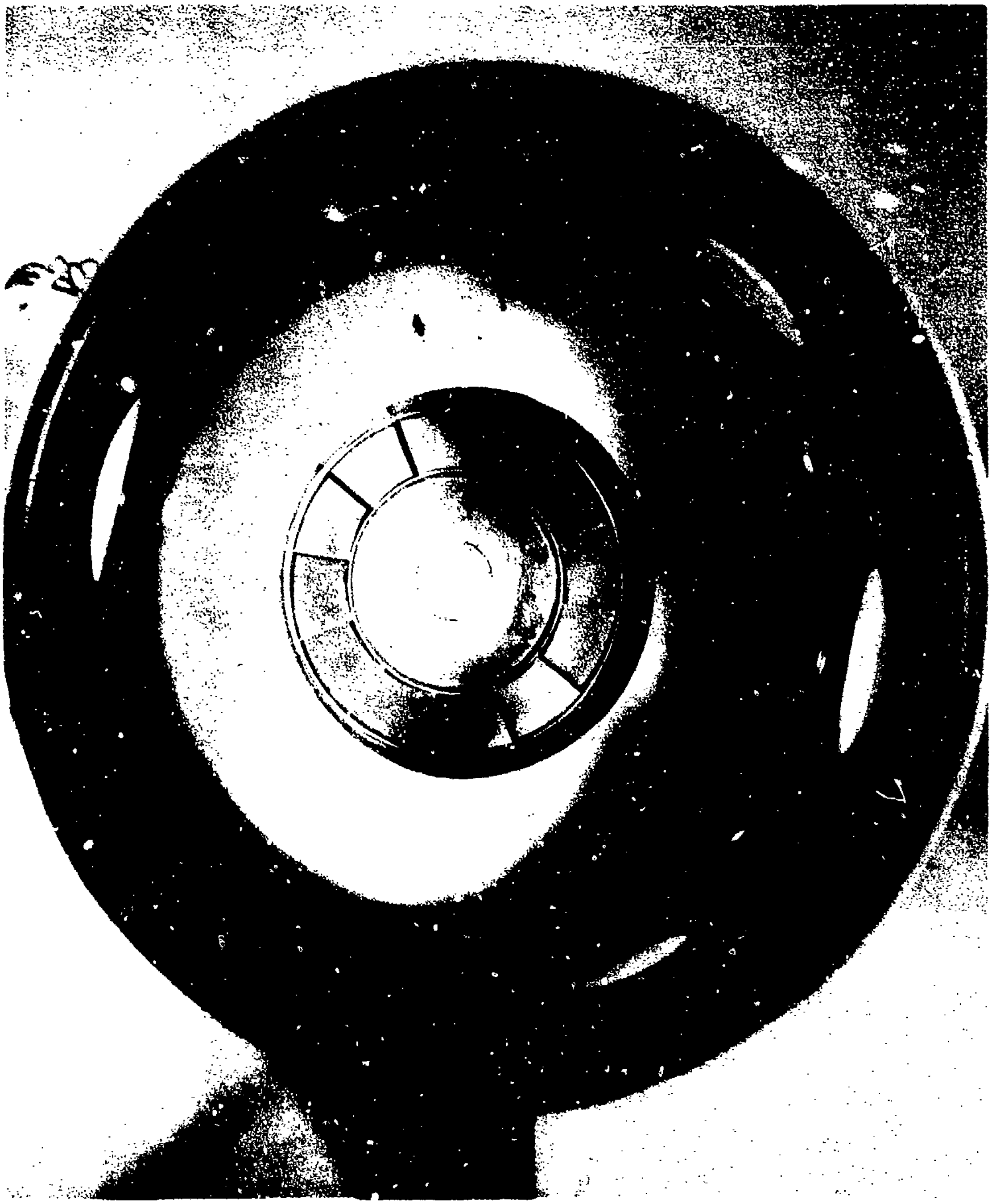


Figure 227. Final Low-Emission Prechamber Combustor Liner, Modification "B", Internal View.

5. The wall fuel film injection hole sizes were increased from sixteen 0.013-inch-diameter holes to sixteen 0.021-inch-diameter holes, which reduced the injector pressure loss and reduced the turbulence of the fuel film at the injector orifices.

The "Final Prechamber Combustor" was operated on both wall fuel film injection and on the centerpoint pressure atomizer during the testing of the initial design and the first two modifications. The last two combustor modifications were operated only on wall fuel film injection. All of the modifications to the "Final Prechamber Combustor" liner were attempts to improve the performance of the wall fuel film injection operating mode of the combustor. The pressure atomizer was operated as a backup system and thus did not receive any specific design attention.

The fourth version of the "Final Prechamber Combustor Liner", Modification "C", was a simple rework of Modification "B", viz., that of closing all twelve of the reaction zone holes. It was intended that, by eliminating the penetrating air jets into the reaction zone, the swirl in that region would not be dissipated. The reaction-zone swirl would increase the mass transfer of reaction products through the swirl vortex into the vaporization tube. An external photograph of Modification "C" can be seen in Figure 228. This version was tested only with the wall fuel film injection system.

The last modification to the "Final Prechamber Combustor Liner", Modification "C", was the installation of a centerbody at the swirler end of the vaporizer tub. This was a change to more closely repeat the design of the preliminary prechamber combustor liner. An internal photograph of this version showing the centerbody is given in Figure 229.

TEST RESULTS

The testing procedure followed for the final combustor configurations is shown in the schematic in Figure 230. The two final configurations, "Modified Conventional" and "Prechamber", were fabricated and instrumented with skin thermocouples. Each was tested at T63 nonregenerative conditions and lean blowout was determined. After the data were analyzed and the duty-cycle emission index values were computed, the liners were either modified and the nonregenerative tests rerun or the final modifications were tested at T63 regenerative conditions, ambient startup conditions, and a set of parametric conditions. The final set of tests was performed on Modification "B" of both final design configurations.

Emission and combustor performance data were recorded at each of the six T63 nonregenerative operating conditions for all three modifications of the "Final Prechamber Combustor Liner" that were

Figure 228. Final Low-Emission Prechamber Combustor Liner, Modification "C".

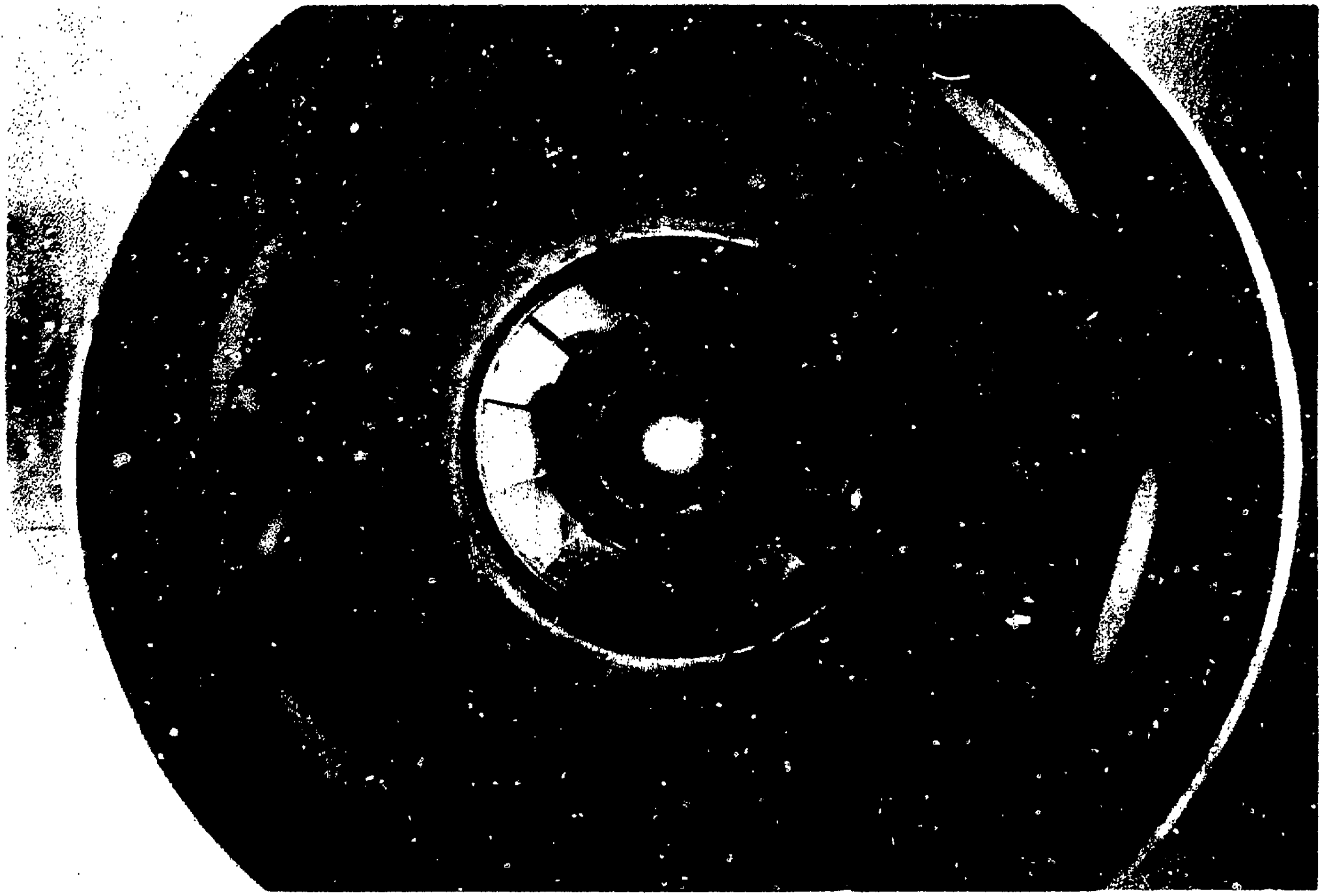


Figure 229. Final Low-Emission Prechamber Combustor Liner, Modification "D", Internal View Showing Centerbody.

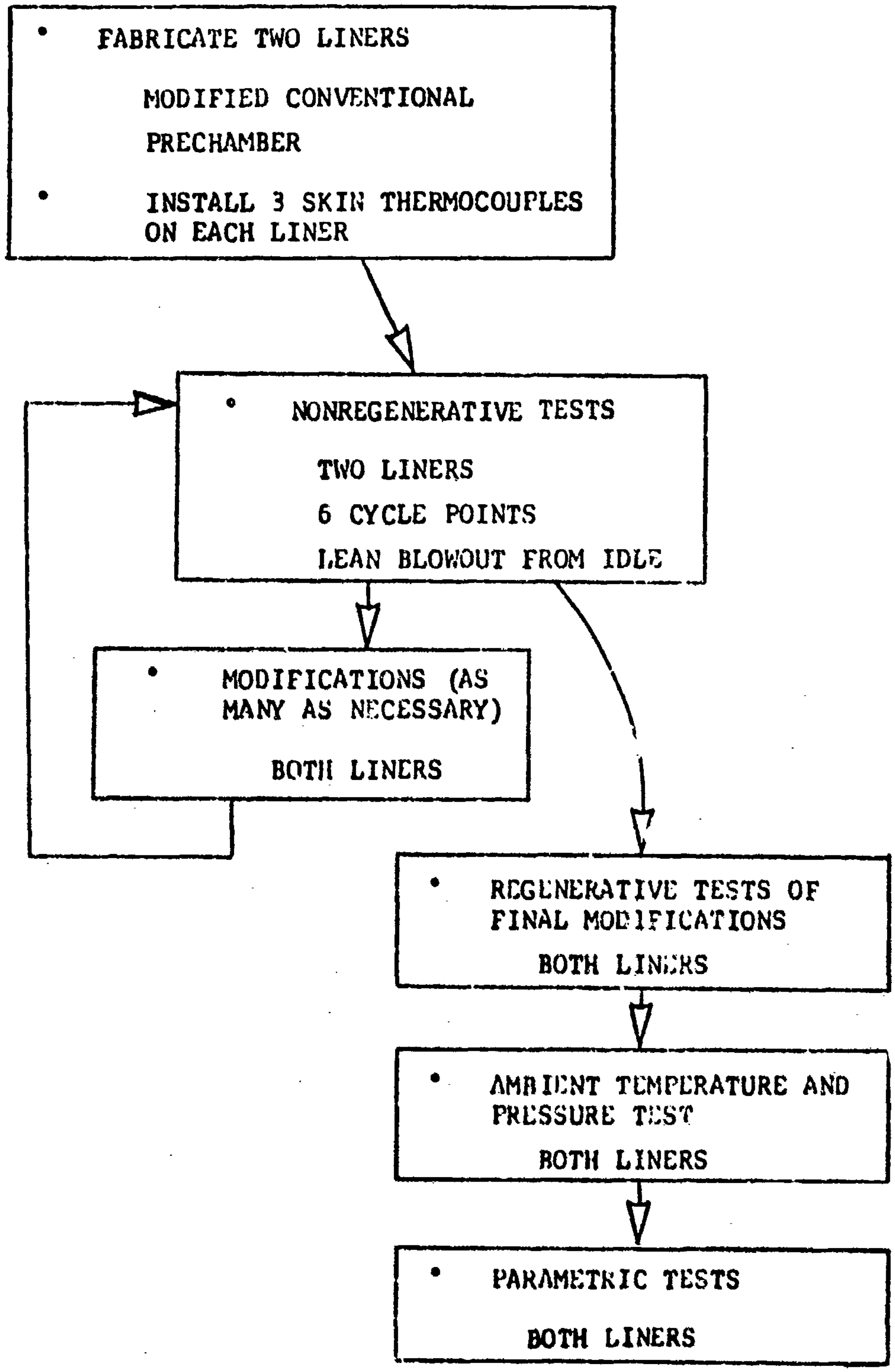


Figure 230. Program Plan for Testing Final Combustors.

operated with the conventional T63 centerpoint pressure atomizer fuel nozzle and for all five versions that were operated on wall fuel film injection. The last two combustor versions were wall fuel film injection tests conducted only at nonregenerative conditions. These tests were final attempts to improve the wall film vaporization system.

The additional instrumentation for the final combustor tests was the set of skin thermocouples located as shown in Figure 231. Data from these thermocouples were recorded for the Initial Design and for Modifications "A" and "B" only.

The following sections present the data acquisition system printouts, emission data (C_xH_y, CO, NO_x, and smoke number), exhaust temperature profile (T_{max}/T_{avg}), and skin thermocouple temperatures for the "Final Prechamber Combustor Liners".

Initial Design

The test data results for the "Final Prechamber Initial Design", are given in Figures 232 through 238 for wall fuel film operation and Figures 239 through 245 for pressure atomizer operation. The chemiluminescent nitrogen oxide measuring instrument was not used during these tests. The emission pressure-loss, and temperature-profile results are summarized in Table LXXIV. As can be seen from these tabulations, the "Prechamber" pressure losses were 1% - 2% higher than those of the "Conventional Liner".

The emission data from Table LXXIV are plotted in Figures 246 through 250. As can be seen in Figure 246, hydrocarbon emissions were nearly eliminated in both fuel system modes of the "Prechamber Liner". Shown in each emissions concentration plot are data from the Conventional T63-A-5A combustor, the "Extended Length, Preliminary Combustor"(which was a conventional combustor with a 6-inch cylindrical extension between the primary and dilution holes), and the "Prechamber Liners" operating under each fuel mode. Carbon monoxide emissions are given in Figure 247 and show the effect of the rich reaction zone operation. The pressure atomizing fuel mode in the "Prechamber Liner"has a definitely increasing CO trend with the increasing overall fuel-air ratios. Nitrogen oxide concentrations were generally lower than for the Conventional Liner, see Figure 248. The pressure atomizer mode of the "Prechamber produced a significant increase in NO_x at maximum power. The wall fuel film "Prechamber" exhibited a smaller NO_x increase at higher power levels than did the Conventional liner. Figure 249 is a plot of CO concentrations vs NO_x concentrations and amplifies how differently the pressure atomizing "Prechamber Liner"produces these emissions than the Conventional, lean-designed liners. Smoke number values are plotted in Figure 250. Even though the "Prechamber Liner" produced very little smoke at the low power points, it was much more sensitive than the Conventional type liners at the higher operating conditions.

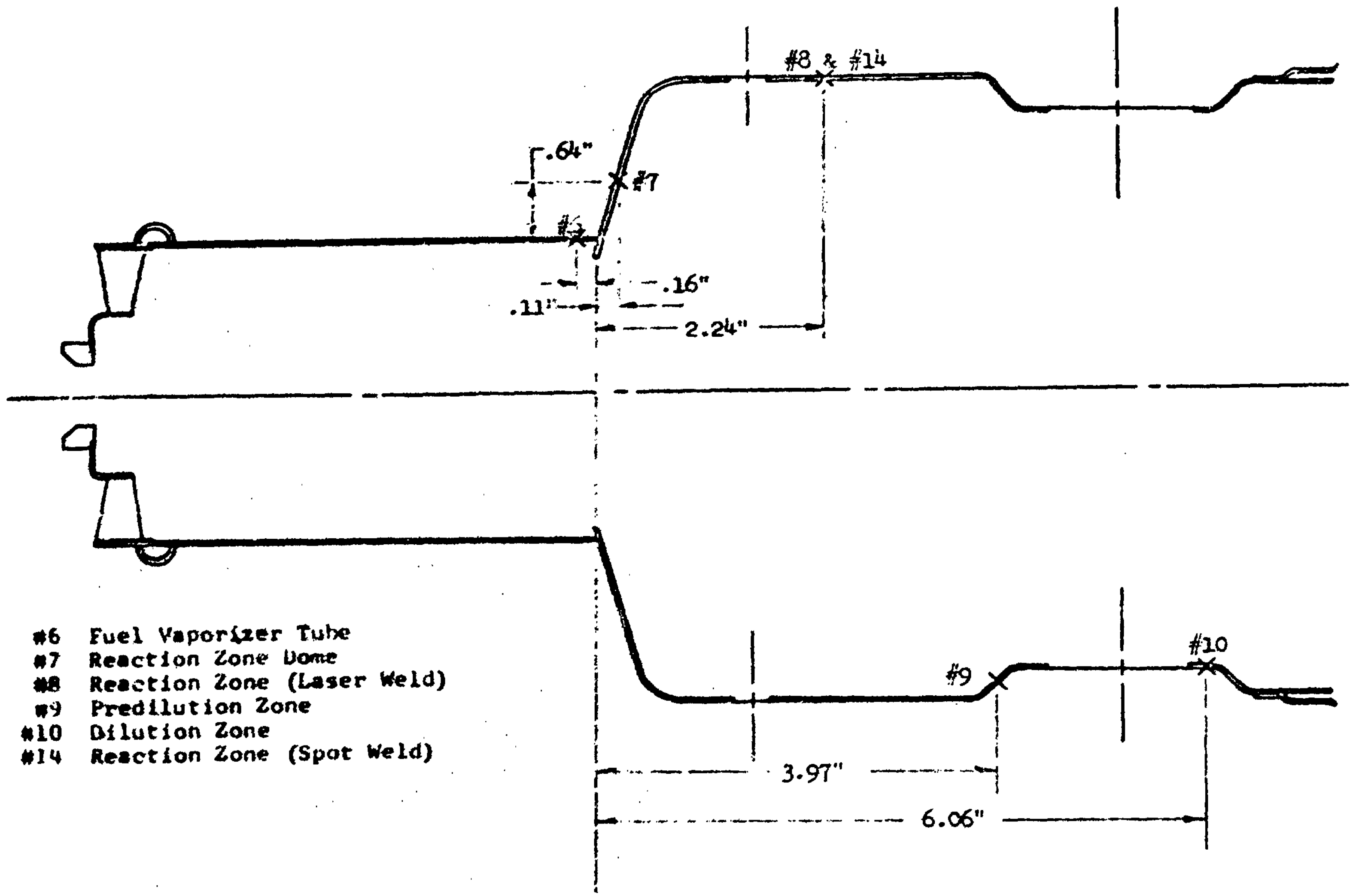


Figure 231. Final Prechamber Combustor Skin Thermocouple Locations.

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T55 COMBUSTOR EXPERIMENTS - RIG E/U 43, TEST SERIES 51, READING #    684
T E3 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE: 8-14-74                        READING WAS TAKEN AT 1615:32 HOURS

CYCLE POINT  1                                            10 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         1.854 LB/SEC     AVG BURNER INLET TEMP   299. DEG F
AVG BURNER INLET PRES  44.7    PSIA      AVG BURNER OUTLET TEMP 1059. DEG F
AVG BURNER DELTA P      5.38    "HG      PRESSURE LOSS             5.98 %
OVERALL F/A RATIO      .01101  (F/P)     FUEL FLOW RATE           73.51 LB/HR
AIR LOAD FACTOR        1.1437            PATTERN FACTOR          .34587
BOT HOT SPOT: # OF # 1321.   DEG F       MAX BOT / AVG BOT       1.2481
FUEL INLET TEMPERATURE 103.  DEG F       FUEL INLET PRESSURE      55.5  PSIA
HEAT LOADING PARAMETER  .31065E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1077.  8 1215. 15 1173. 19  958. 24  882. 27 1054. 36 1321.
ANNULUS 2   4 1058.  7 1141. 16 1151. 21  824. 25  785. 34 1308. 37 1281.
ANNULUS 3   5 1085. 14 1020. 17 1010. 22  755. 26  814. 35 1243. 38 1196.

LEFT SIDE               *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE             44.63   PSIA    TOTAL PRESSURE          44.79   PSIA
STATIC PRESSURE            44.47   PSIA    STATIC PRESSURE         44.47   PSIA
VELOCITY DELTA P            .43    "HG     VELOCITY DELTA P          .40    "HG
AIR TEMPERATURE            299.  DEG F     AIR TEMPERATURE          295.  DEG F
AIR VELOCITY             114.81 FT/SEC     AIR VELOCITY           115.30 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            -.136    "HG

AIR FLOW DATA: P-METER 144.7 PSIA   DELTA P= 1.57 "HG    T-METER  87. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY         271.     HZ     VOLUMETRIC FLOW RATE  11.01 GAL/HR
FUEL PRESSURE AT F/M  170.9    PSIA     FUEL TEMP AT F/M          86.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   42.83 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                43.87 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   5.28 "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.108 %      O2   18.482 %      CO    432.3 PPM      C-H       8.3 PPM
 NO      8.4 PPM   NO2     11.8 PPM   NOX     16.5 PPM (NO(NDIR) + NO2(NDUV))
 NO       .8 PPM   NO2       .8 PPM   NOX       .8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  30.28                      CHX=     .01
                  CHEMILUMINESCENCE NOX=     .08,   NDIR + NDUV NOX=   2.84

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010410
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.9097 %
   CHECK ON F/A RATIO- F/A = .010642 F/C C2, CALCULATED C2 = 17.927 %

SMOKE INDEX:  2.47
SALTZMAN NOX = 19.3          PPM   E.I.= 2.81
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Figure 232. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 81, READING #    885
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE:  6-14-72                      READING WAS TAKEN AT 165111B HOURS

CYCLE POINT  6                                          25 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.204 LB/SEC     AVG BURNER INLET TEMP   384. DEG F
AVG BURNER INLET PRES  54.4    PSIA      AVG BURNER OUTLET TEMP 1180. DEG F
AVG BURNER DELTA P      6.45    "HG      PRESSURE LOSS             5.83 %
OVERALL F/A RATIO      .01218  (F/M)     FUEL FLOW RATE           95.99 LB/HR
AIR LOAD FACTOR        1.1559            PATTERN FACTOR          .36852
BOT HOT SPOT:  = 34 = 1485.  DEG F       MAX BOT / AVG BOT       1.2588
FUEL INLET TEMPERATURE 121.  DEG F       FUEL INLET PRESSURE       73.2  PSIA
HEAT LOADING PARAMETER  .34218E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1167.  6 1314. 15 1338. 19 1114. 24  888. 27 1179. 36 1394.
ANNULUS 2   4 1168.  7 1232. 16 1294. 21  908. 25  873. 34 1485. 37 1411.
ANNULUS 3   5 1281. 14 1152. 17 1165. 22  858. 26  923. 35 1482. 38 1335.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           54.35    PSIA    TOTAL PRESSURE         54.41    PSIA
STATIC PRESSURE          54.06    PSIA    STATIC PRESSURE        54.09    PSIA
VELOCITY DELTA P           .68     "HG    VELOCITY DELTA P         .67     "HG
AIR TEMPERATURE          354.   DEG F     AIR TEMPERATURE         354.   DEG F
AIR VELOCITY            123.39 FT/SEC     AIR VELOCITY           120.03 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)):         -.128    "HG

AIR FLOW DATA: P-REF= 104.8 PSIA   DELTA P= 2.17 "HG    T-REF=  74. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       383.      HZ     VOLUMETRIC FLOW RATE  15.43 GAL/HR
FUEL PRESSURE AT F/M   165.0    PSIA      FUEL TEMP AT F/M         86.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     51.21 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              53.34 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.30  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.481 %      O2  18.00P %      CO    242.5 PPM      CHX       .8 PPM
 NO      15.5 PPM  NO2      9.7 PPM  NOX     25.2 PPM (NO(NDIR) + NO2(NDUV))
 NO       .8 PPM   NO2       .8 PPM  NOX       .8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.02                    CHX=    .28
                  CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   3.35

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .011304
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.8174 %
   CHECK ON F/A RATIO- F/A = .011598 W/O O2, CALCULATED O2 = 17.038 %

SMOKE INDEX:  1.78
SALTZMAN NOX = 26.2               PPM      E.I. = 3.48
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Figure 233. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 51, READING #    686
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE: 6-14-72                        READING WAS TAKEN AT 1730:16 HOURS

CYCLE POINT  5                                           40 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.548 LB/SEC     AVG BURNER INLET TEMP    398. DEG F
AVG BURNER INLET PRES  63.6    PSIA      AVG BURNER OUTLET TEMP 1293. DEG F
AVG BURNER DELTA P      7.58    "HG      PRESSURE LOSS             5.86 %
OVERALL F/A RATIO      .01300  (F/M)     FUEL FLOW RATE          119.23 LB/HR
AIR LOAD FACTOR        1.1731            PATTERN FACTOR           .28937
BOT HOT SPOT: # 37 = 1552.  DEG F        MAX BOT / AVG BOT       1.2004
FUEL INLET TEMPERATURE 130.  DEG F       FUEL INLET PRESSURE      93.0  PSIA
HEAT LOADING PARAMETER  .36342E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1310.  6 1451. 15 1491. 19 1207. 24  953. 27 1262. 36 1542.
ANNULUS 2    4 1290.  7 1391. 16 1461. 21  984. 25  959. 34 1537. 37 1552.
ANNULUS 3    5 1327. 14 1289. 17 1274. 22  921. 26 1009. 35 1484. 39 1459.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE         63.56    PSIA     TOTAL PRESSURE          63.64  PSIA
STATIC PRESSURE        63.17    PSIA     STATIC PRESSURE         63.34  PSIA
VELOCITY DELTA P         .81    "HG      VELOCITY DELTA P          .61  "HG
AIR TEMPERATURE         398.   DEG F     AIR TEMPERATURE          398.  DEG F
AIR VELOCITY          135.77 FT/SEC      AIR VELOCITY           117.99 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.161   "HG

AIR FLOW DATA: P-REF= 104.4 PSIA   DELTA P= 2.92 "HG   T-REF=  73. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      438.      HZ     VOLUMETRIC FLOW RATE  19.17 GAL/HR
FUEL PRESSURE AT F/M   157.9    PSIA     FUEL TEMP AT F/M        88.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    59.88 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             62.30 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.50 "HG  (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.600 %     O2  17.500 %     CO   194.1 PPM     CHX       .0 PPM
 NO     18.3 PPM  NO2    13.3 PPM  NOX    31.6 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2      .0 PPM  NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  14.63                CHX=     .00
                  CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   3.91

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .012423
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6437 %
   CHECK ON F/A RATIO- F/A = .012504 W/O O2, CALCULATED O2 = 17.363 %

SMOKE INDEX: 2.89
SALTZMAN NOX = 32.5              PPM  E.I.= 4.02
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Figure 234. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative 40% Power.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 51, READING # 687
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE: 6-14-72 READING WAS TAKEN AT 1804:37 HOURS

CYCLE POINT 4 55 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.778 LB/SEC	AVG BURNER INLET TEMP	431. DEG F
AVG BURNER INLET PRES	71.2 PSIA	AVG BURNER OUTLET TEMP	1385. DEG F
AVG BURNER DELTA P	8.42 "HG	PRESSURE LOSS	5.81 %
OVERALL F/A RATIO	.01441 (F/M)	FUEL FLOW RATE	144.17 LB/HR
AIR LOAD FACTOR	1.1648	PATTERN FACTOR	.37153
BOT HOT SPOT: # 37 = 1739. DEG F		MAX BOT / AVG BOT	1.2559
FUEL INLET TEMPERATURE	133. DEG F	FUEL INLET PRESSURE	114.3 PSIA

HEAT LOADING PARAMETER .39265E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1397.	6	1605.	15	1462.	19	1322.	24	1035.	27	1336.	36	1692.
ANNULUS 2	4	1324.	7	1638.	16	1475.	21	1067.	25	1022.	34	1656.	37	1739.
ANNULUS 3	5	1288.	14	1307.	17	1434.	22	990.	26	1070.	35	1591.	39	1630.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	71.13 PSIA	TOTAL PRESSURE	71.23 PSIA
STATIC PRESSURE	70.72 PSIA	STATIC PRESSURE	70.81 PSIA
VELOCITY DELTA P	.83 "HG	VELOCITY DELTA P	.85 "HG
AIR TEMPERATURE	431. DEG F	AIR TEMPERATURE	431. DEG F
AIR VELOCITY	133.05 FT/SEC	AIR VELOCITY	134.56 FT/SEC

DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.193 "HG

AIR FLOW DATA: P-REF= 104.1 PSIA DELTA P= 3.51 "HG T-REF= 77. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	530. HZ	VOLUMETRIC FLOW RATE	23.20 GAL/HR
FUEL PRESSURE AT F/M	148.7 PSIA	FUEL TEMP AT F/M	89. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 67.05 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 70.03 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 8.32 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2	2.725 %	O2	17.400 %	CO	179.2 PPM	CHX	.5 PPM
NO	28.1 PPM	NO2	14.7 PPM	NOX	42.8 PPM	[NO(NDIR) + NO2(NDUV)]	
NO	.0 PPM	NO2	.0 PPM	NOX	.0 PPM	[CHEMILUMINESCENCE]	

EMISSIONS INDEX, LB/1000 LB FUEL: CO= 12.19 CHX= .05
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 4.78

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .012959
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.6740 %
CHECK ON F/A RATIO- F/A = .013987 W/O O2, CALCULATED O2 = 17.189 %

SMOKE INDEX: 10.47
SALTZMAN NOX = 40.7 PPM E.I. = 4.55

Figure 235. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 51, READING #     688
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE:  6-14-72                     READING WAS TAKEN AT 1842:26 HOURS

CYCLE POINT  3                                       75 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.940 LB/SEC    AVG BURNER INLET TEMP    473. DEG F
AVG BURNER INLET PRES  80.2    PSIA     AVG BURNER OUTLET TEMP 1563. DEG F
AVG BURNER DELTA P      8.60    "HG     PRESSURE LOSS              5.27 %
OVERALL F/A RATIO      .01675  (F/P)    FUEL FLOW RATE          177.26 LB/HR
AIR LOAD FACTOR        1.1193           PATTERN FACTOR          .32388
BOT HOT SPOT:  # 34 = 1916.  DEG F      MAX BOT / AVG BOT       1.2259
FUEL INLET TEMPERATURE 145.  DEG F      FUEL INLET PRESSURE      145.7   PSIA
HEAT LOADING PARAMETER  .42850E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1636,  6 1775, 15 1720, 19 1468, 24 1118, 27 1455, 36 1875.
ANNULUS 2   4 1481,  7 1825, 16 1738, 21 1175, 25 1095, 34 1916, 37 1963.
ANNULUS 3   5 1499, 14 1528, 17 1665, 22 1085, 26 1159, 35 1863, 3C 1918.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE         80.16    PSIA    TOTAL PRESSURE          80.24   PSIA
STATIC PRESSURE        79.71    PSIA    STATIC PRESSURE         79.78   PSIA
VELOCITY DELTA P         .92     "HG    VELOCITY DELTA P          .93    "HG
AIR TEMPERATURE         473.   DEG F    AIR TEMPERATURE          473.  DEG F
AIR VELOCITY          134.41 FT/SEC     AIR VELOCITY           135.47 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]     -.160    "HG

AIR FLOW DATA: P-REF= 103.5 PSIA   DELTA P= 3.99 "HG   T-REF=  88. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      654.      HZ    VOLUMETRIC FLOW RATE  28.55 GAL/HR
FUEL PRESSURE AT F/M  172.4    PSIA     FUEL TEMP AT F/M          98.  DEG F

             ** MISCELLANEOUS TRANSDUCER READ NGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    75.97 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             78.78 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                8.52  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2    2.801 %     O2   17.200 %     CO    166.8 PPM     CHX      1.1 PPM
 NO     32.3 PPM  NO2     18.7 PPM  NOX     51.1 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   9.79                CHX=     .18
              CHEMILUMINESCENCE NOX=    .00,     NDIR + NDUV NOX=    4.98

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .013365
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6924 %
   CHECK ON F/A RATIO- F/A = .013438 W/O O2, CALCULATED O2 = 17.084 %

SMOKE INDEX: 26.03
SALTZMAN NOX = 52.1              PPM  E.I.: 5.02
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Figure 236. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative 75% Power.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 51, READING # 680
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE: 6-14-72 READING WAS TAKEN AT 1908:39 HOURS

CYCLE POINT 2 100 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	3.154 LB/SEC	AVG BURNER INLET TEMP	525. DEG F
AVG BURNER INLET PRES	92.7 PSIA	AVG BURNER OUTLET TEMP	1790. DEG F
AVG BURNER DELTA P	8.96 "HG	PRESSURE LOSS	4.75 %
OVERALL F/A RATIO	.01972 (F/M)	FUEL FLOW RATE	223.98 LB/HR
AIR LOAD FACTOR	1.0675	PATTERN FACTOR	.31513
BOT HOT SPOT: # 34 = 2189. DEG F		MAX BOT / AVG BOT	1.2226
FUEL INLET TEMPERATURE	159. DEG F	FUEL INLET PRESSURE	197.9 PSIA

HEAT LOADING PARAMETER .46821E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1899.	6	1936.	15	1928.	19	1745.	24	1296.	27	1638.	36	2173.
ANNULUS 2	4	1692.	7	2078.	16	2037.	21	1369.	25	1252.	34	2189.	37	2104.
ANNULUS 3	5	1702.	14	1813.	17	1985.	22	1280.	26	1302.	35	2158.	38	2020.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	92.69 PSIA	TOTAL PRESSURE	92.79 PSIA
STATIC PRESSURE	92.22 PSIA	STATIC PRESSURE	92.25 PSIA
VELOCITY DELTA P	.97 "HG	VELOCITY DELTA P	1.09 "HG
AIR TEMPERATURE	526. DEG F	AIR TEMPERATURE	525. DEG F
AIR VELOCITY	132.11 FT/SEC	AIR VELOCITY	140.31 FT/SEC

DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.185 "HG

AIR FLOW DATA: P-REF= 103.0 PSIA DELTA P= 4.63 "HG T-REF= 81. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	831. HZ	VOLUMETRIC FLOW RATE	36.11 GAL/HR
FUEL PRESSURE AT F/M	268.5 PSIA	FUEL TEMP AT F/M	92. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 88.34 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 91.31 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 8.87 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 3.313 % O2 16.500 % CO 116.2 PPM CHX 1.6 PPM
NO 69.6 PPM NO2 25.3 PPM NOX 94.9 PPM [NO(NDIR) + NO2(NDUV)]
NO .0 PPM NO2 .0 PPM NOX .0 PPM [CHEMILUMINESCENCE]
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 5.81 CHX= .08
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 7.79

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .015723
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.7931 %
CHECK ON F/A RATIO- F/A = .015815 W/O O2, CALCULATED O2 = 16.374 %

SMOKE INDEX: 61.29
SALTZMAN NOX = 81.1 PPM E.I. = 6.66

REMARKS: Saltzman Sample was Diluted - NO_x Reading is Low

Figure 237. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative 100% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 51, READING #    691
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON WALL FILM VAPORIZER
TEST DATE:  6-14-72                        READING WAS TAKEN AT 1953112 HOURS

CYCLE POINT  1                                             10 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.861 LB/SEC     AVG BURNER INLET TEMP     299. DEG F
AVG BURNER INLET PRES   45.0    PSIA      AVG BURNER OUTLET TEMP    728. DEG F
AVG BURNER DELTA P       4.81    "HG      PRESSURE LOSS             5.26 %
OVERALL F/A RATIO       .00655  (F/P)     FUEL FLOW RATE           43.86 LB/HR
AIR LOAD FACTOR         1.1400            PATTERN FACTOR           .42399
BOT HOT SPOT:  # 36 =   909.   DEG F      MAX BOT / AVG BOT        1.2495
FUEL INLET TEMPERATURE 117.   DEG F       FUEL INLET PRESSURE      47.8   PSIA
HEAT LOADING PARAMETER   .18908E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2  792.  6  785. 15  758. 19  616. 24  624. 27  775. 36  909.
ANNULUS 2    4  734.  7  767. 16  723. 21  607. 25  625. 34  816  37  869.
ANNULUS 3    5  675. 14  703. 17  652. 22  589. 26  641. 35  821. 39  802.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          44.97    PSIA    TOTAL PRESSURE           44.97   PSIA
STATIC PRESSURE         44.70    PSIA    STATIC PRESSURE          44.73   PSIA
VELOCITY DELTA P          .55     "HG    VELOCITY DELTA P           .50    "HG
AIR TEMPERATURE         299.   DEG F     AIR TEMPERATURE          308.   DEG F
AIR VELOCITY           125.82 FT/SEC     AIR VELOCITY            119.68 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.001    "HG

AIR FLOW DATA: P-REF= 105.8 PSIA    DELTA P= 1.55 "HG    T-REF=  81. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        182.       HZ     VOLUMETRIC FLOW RATE    7.07 GAL/HR
FUEL PRESSURE AT F/M    150.3      PSIA     FUEL TEMP AT F/M         91.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     42.61 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              44.32 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 4.81  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX =X                        PPM
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REMARKS:
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Stable Point Before Blowout
LBO at F/A= .0062

Figure 238. Final Prechamber Liner Initial Design on Wall Fuel Injection at Nonregenerative Lean Blow Out.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 52, READING #    700
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE:  6-15-72                        READING WAS TAKEN AT 1813:40 HOURS

CYCLE POINT  1                                            10 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.859 LB/SEC     AVG BURNER INLET TEMP   298. DEG F
AVG BURNER INLET PRES   45.2    PSIA      AVG BURNER OUTLET TEMP 1089. DEG F
AVG BURNER DELTA P       5.63   "HG       PRESSURE LOSS            6.11 %
OVERALL F/A RATIO      .01078  (F/M)      FUEL FLOW RATE          72.14 LB/HR
AIR LOAD FACTOR         1.1317            PATTERN FACTOR         .21510
BOT HOT SPOT:  # 36 = 1223.  DEG F        MAX BOT / AVG BOT      1.1546
FUEL INLET TEMPERATURE 133.  DEG F        FUEL INLET PRESSURE    188.1   PSIA
HEAT LOADING PARAMETER  .30941E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
          ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1078.  6 1109. 15 1111. 19  969. 24  980. 27 1183. 36 1223.
ANNULUS 2  4  987.  7 1089. 16 1124. 21  903. 25  947. 34 1158. 37 1216.
ANNULUS 3  5  959. 14  997. 17 1032. 22  895. 26  972. 35 1091. 39 1217.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          45.18    PSIA     TOTAL PRESSURE          45.22   PSIA
STATIC PRESSURE         44.91    PSIA     STATIC PRESSURE         45.03   PSIA
VELOCITY DELTA P          .55    "HG      VELOCITY DELTA P          .38   "HG
AIR TEMPERATURE          298.  DEG F      AIR TEMPERATURE          298.  DEG F
AIR VELOCITY           125.31 FT/SEC      AIR VELOCITY           104.39 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.001   "HG

AIR FLOW DATA: P-REF= 105.2 PSIA   DELTA P= 1.58 "HG   T-REF=  90. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      268.      HZ      VOLUMETRIC FLOW RATE  11.08 GAL/HR
FUEL PRESSURE AT F/M   289.0    PSIA      FUEL TEMP AT F/M         98.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    42.44 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             44.59 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.59  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2   1.961 %     O2  18.100 %     CO     74.6 PPM     CHX       .4 PPM
 NO      9.8 PPM  NO2      4.8 PPM  NOX    14.7 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   6.76                  CHX=    .05
                  CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   2.16

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .009581
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8894 %
   CHECK ON F/A RATIO- F/A = .009428 W/O O2, CALCULATED O2 = 18.263 %

SMOKE INDEX: X
SALTZMAN NOX = X                   PPM
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Figure 239. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 43, TEST SERIES 52, READING #    695
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE: 5-15-72                    READING WAS TAKEN AT 151637 HOURS

CYCLE POINT  6                                        25 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.266 LB/SEC     AVG BURNER INLET TEMP    353. DEG F
AVG BURNER INLET PRES   54.2    PSIA      AVG BURNER OUTLET TEMP 1193. DEG F
AVG BURNER DELTA P       7.16   "HG       PRESSURE LOSS             6.49 %
OVERALL F/A RATIO      .01210  (F/P)      FUEL FLOW RATE           98.66 LB/HR
AIR LOAD FACTOR         1.1929            PATTERN FACTOR          .18264
HOT HOT SPOT:  # 36 = 1346.   DEG F       MAX BOT / AVG BOT       1.1285
FUEL INLET TEMPERATURE 116.   DEG F       FUEL INLET PRESSURE      234.7  PSIA
HEAT LOADING PARAMETER  .35317E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1191.  6 1305. 15 1240. 19 1171. 24 1072. 27 1343. 36 1346.
ANNULUS 2   4 1133.  7 1277. 16 1257. 21 1016. 25 1067. 34 1278. 37 1335.
ANNULUS 3   5 1038. 14 1126. 17 1198. 22  996. 26 1091. 35 1267. 39 1303.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           54.13    PSIA    TOTAL PRESSURE          54.10   PSIA
STATIC PRESSURE          53.59    PSIA    STATIC PRESSURE         53.80   PSIA
VELOCITY DELTA P          1.10    "HG     VELOCITY DELTA P          .79   "HG
AIR TEMPERATURE          353.   DEG F     AIR TEMPERATURE         354.   DEG F
AIR VELOCITY            167.71 FT/SEC     AIR VELOCITY           142.17 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.107   "HG

AIR FLOW DATA: P-REF= 104.8 PSIA    DELTA P= 2.38 "HG    T-REF=  94. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       363.      HZ     VOLUMETRIC FLOW RATE  15.87 GAL/HR
FUEL PRESSURE AT F/M   271.5     PSIA     FUEL TEMP AT F/M        87.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     50.64 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              53.14 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 7.11  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.570 %     O2  17.700 %     CO    123.7 PPM     CHX       .3 PPM
 NO     19.0 PPM   NO2     7.6 PPM  NOX    26.7 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2      .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.01                 CHX=    .03
                   CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   3.54

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011378
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7424 %
   CHECK ON F/A RATIO- F/A = .011383 W/O O2, CALCULATED O2 = 17.699 %

SMOKE INDEX:  0.00
SALTZMAN NOX = 31.3               PPM    E.I.= 4.15
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Figure 240. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 52, READING #    696
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE:  6-15-72                        READING WAS TAKEN AT 1550:11 HOURS

CYCLE POINT  5                                             40 % POWER SETTING

                       ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW             2.516 LB/SEC    AVG BURNER INLET TEMP    395. DEG F
AVG BURNER INLET PRES  63.2    PSIA    AVG BURNER OUTLET TEMP 1298. DEG F
AVG BURNER DELTA P      8.04     "HG    PRESSURE LOSS                6.25 %
OVERALL F/A RATIO      .01311   (F/F)   FUEL FLOW RATE            118.75 LB/HR
AIR LOAD FACTOR        1.1652           PATTERN FACTOR             .18308
BOT HOT SPOT:  # 36 = 1463.  DEG F     MAX BOT / AVG BOT         1.1273
FUEL INLET TEMPERATURE 122.   DEG F     FUEL INLET PRESSURE       272.1   PSIA
HEAT LOADING PARAMETER  .36455E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1324.  6 1418. 15 1321. 19 1225. 24 1184. 27 1452. 36 1463.
ANNULUS 2    4 1208.  7 1421. 16 1344. 21 1129. 25 1156. 34 1385. 37 1439.
ANNULUS 3    5 1228. 14 1199. 17 1277. 22 1115. 26 1172. 35 1356. 39 1447.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          63.10    PSIA    TOTAL PRESSURE           63.20    PSIA
STATIC PRESSURE         62.67    PSIA    STATIC PRESSURE          62.95    PSIA
VELOCITY DELTA P          .87     "HG    VELOCITY DELTA P           .52     "HG
AIR TEMPERATURE          395.   DEG F    AIR TEMPERATURE           396.   DEG F
AIR VELOCITY          141.58 FT/SEC     AIR VELOCITY            109.48 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.215     "HG

AIR FLOW DATA: P-REF= 103.9 PSIA   DELTA P= 2.98 "HG    T-REF=  96. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       437.       HZ    VOLUMETRIC FLOW RATE  19.13 GAL/HR
FUEL PRESSURE AT F/M  329.7    PSIA    FUEL TEMP AT F/M            98.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    59.20 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                62.22 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   7.03  "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    2.550 %      O2  17.500 %      CO    141.0 PPM      CHX       .4 PPM
 NO     28.8 PPM  NO2      8.1 PPM  NOX    36.9 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.53                 CHX=     .04
                CHEMILUMINESCENCE NOX=      .00,    NDIR + NDUV NOX=    4.53

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:           .012206
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7222 %
   CHECK ON F/A RATIO- F/A = .012242 W/O O2, CALCULATED O2 = 17.437 %

SMOKE INDEX:  0.00
SALTZMAN NOX =  42.8              PPM    E.I. = 5.25
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Figure 241. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative 40% Power.

T53 COMBUSTOR EXPERIMENTS - RIG E/U 43, TEST SERIES 52, READING # 697
T 53 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE: 6-15-72 READING WAS TAKEN AT 1658151 HOURS

CYCLE POINT 4 55 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.759 LB/SEC	AVG BURNER INLET TEMP	429. DEG F
AVG BURNER INLET PRES	71.2 PSIA	AVG BURNER OUTLET TEMP	1421. DEG F
AVG BURNER DELTA P	8.83 "HG	PRESSURE LOSS	6.09 %
OVERALL F/A RATIO	.01449 (F/M)	FUEL FLOW RATE	143.88 LB/HR
AIR LOAD FACTOR	1.1550	PATTERN FACTOR	.15930
BOT HOT SPOT: # 27 = 1579.	DEG F	MAX BOT / AVG BOT	1.1112
FUEL INLET TEMPERATURE 137.	DEG F	FUEL INLET PRESSURE	312.0 PSIA

HEAT LOADING PARAMETER .39164E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1437.	6	1510.	15	1499.	19	1339.	24	1348.	27	1579.	36	1518.
ANNULUS 2	4	1369.	7	1496.	16	1524.	21	1210.	25	1272.	34	1545.	37	1531.
ANNULUS 3	5	1341.	14	1385.	17	1418.	22	1211.	26	1296.	35	1468.	39	1546.

LEFT SIDE	*** AIR INLET TUBE	CONDITIONS ***	RIGHT SIDE
TOTAL PRESSURE	71.22 PSIA	TOTAL PRESSURE	71.22 PSIA
STATIC PRESSURE	70.97 PSIA	STATIC PRESSURE	70.95 PSIA
VELOCITY DELTA P	.51 "HG	VELOCITY DELTA P	.55 "HG
AIR TEMPERATURE	429. DEG F	AIR TEMPERATURE	429. DEG F
AIR VELOCITY	104.01 FT/SEC	AIR VELOCITY	107.44 FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.003 "HG

AIR FLOW DATA: P-REF= 103.0 PSIA DELTA P= 3.61 "HG T-REF= 93. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	531. HZ	VOLUMETRIC FLOW RATE	23.24 GAL/HR
FUEL PRESSURE AT F/M	370.5 PSIA	FUEL TEMP AT F/M	94. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 66.88 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 70.26 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 8.83 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 2.500 % O2 17.300 % CO 170.9 PPM CHX .6 PPM
NO 33.7 PPM NO2 11.5 PPM NOX 45.2 PPM (NO(NDIR) + NO2(NDUV))
NO .0 PPM NO2 .0 PPM NOX .0 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 11.57 CHX= .06
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 5.03

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .012140
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.6558 %
CHECK ON F/A RATIO- F/A = .012024 W/O O2, CALCULATED O2 = 17.503 %

SMOKE INDEX: 4.90
SALTZMAN NOX = 50.6 PPM E.I. = 5.63

Figure 242. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative 55% Power.

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T53 COMBUSTOR EXPERIMENTS - RIG B/U #3, TEST SERIES 52, READING #    698
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE:  6-15-72                       READING WAS TAKEN AT 1722:20 HOURS

CYCLE POINT  3                                          75 % POWER SETTING

                       ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.986 LB/SEC     AVG BURNER INLET TEMP   473. DEG F
AVG BURNER INLET PRES   80.6    PSIA      AVG BURNER OUTLET TEMP 1579. DEG F
AVG BURNER DELTA P       9.50    "HG      PRESSURE LOSS             5.83 %
OVERALL F/A RATIO       .01653  (F/M)     FUEL FLOW RATE          177.87 LB/HR
AIR LOAD FACTOR         1.1330            PATTERN FACTOR          .18902
BOT HOT SPOT:  #  7 = 1788.  DEG F        MAX BOT / AVG BOT       1.1324
FUEL INLET TEMPERATURE 143.  DEG F        FUEL INLET PRESSURE      387.9  PSIA
HEAT LOADING PARAMETER  .42803E+07 BTU/HOUR/ATM/CUBIC FOOT

                      **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1619.  6 1770. 15 1570. 19 1501. 24 1417. 27 1734. 36 1711.
ANNULUS 2    4 1522.  7 1788. 16 1655. 21 1362. 25 1337. 34 1689. 37 1733.
ANNULUS 3    5 1518. 14 1515. 17 1588. 22 1367. 26 1394. 35 1616. 39 1760.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE            80.55    PSIA   TOTAL PRESSURE          80.58   PSIA
STATIC PRESSURE           79.82    PSIA   STATIC PRESSURE         80.15   PSIA
VELOCITY DELTA P           1.49     "HG   VELOCITY DELTA P          .87    "HG
AIR TEMPERATURE           473.   DEG F    AIR TEMPERATURE          473.   DEG F
AIR VELOCITY             171.16 FT/SEC    AIR VELOCITY            130.96 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.064    "HG

AIR FLOW DATA: P-REF= 102.2 PSIA    DELTA P= 4.27 "HG    T-REF=  93. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        659.      HZ    VOLUMETRIC FLOW RATE  28.76 GAL/HR
FUEL PRESSURE AT F/M   473.7    PSIA      FUEL TEMP AT F/M          86.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    75.87 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             79.24 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                9.53  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.051 %     O2   16.700 %    CO    101.0 PPM     CHX      .0 PPM
 NO     35.2 PPM  NO2     15.2 PPM  NOX     50.3 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.41                 CHX=     .00
                   CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=   4.01

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .013809
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6603 %
   CHECK ON F/A RATIO- F/A = .013686 W/O O2, CALCULATED O2 = 17.012 %

SMOKE INDEX: 14.98
SALTZMAN NOX = 57.1              PPM  E.I. = 5.57
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Figure 243. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative 75% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG P/U 43, TEST SERIES 52, READING #    699
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE:  6-15-72                       READING WAS TAKEN AT 1745:46 HOURS

CYCLE POINT  2                                           100 % POWER SETTING

                      ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         3.226 LB/SEC     AVG BURNER INLET TEMP    524. DEG F
AVG BURNER INLET PRES  91.0    PSIA      AVG BURNER OUTLET TEMP 1796. DEG F
AVG BURNER DELTA P      9.82    "HG      PRESSURE LOSS              5.30 %
OVERALL F/A RATIO      .01957  (F/A)     FUEL FLOW RATE           227.20 LB/HR
AIR LOAD FACTOR        1.1112            PATTERN FACTOR            .31965
BOT HOT SPOT:  #  7 = 2203.   DEG F      MAX BOT / AVG BOT         1.2265
FUEL INLET TEMPERATURE 157.   DEG F      FUEL INLET PRESSURE       317.7   PSIA
HEAT LOADING PARAMETER  .48390E+07 BTU/HOUR-ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1844.  6 2019. 15 1845. 19 1767. 24 1618. 27 1963. 36 1805.
ANNULUS 2  4 1671.  7 2243. 16 1899. 21 1550. 25 1523. 34 1936. 37 1857.
ANNULUS 3  5 1724. 14 1633. 17 1870. 22 1548. 26 1635. 35 1856. 39 1824.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE           90.94    PSIA    TOTAL PRESSURE           91.11   PSIA
STATIC PRESSURE          90.49    PSIA    STATIC PRESSURE          90.64   PSIA
VELOCITY DELTA P           .92     "HG    VELOCITY DELTA P           .94    "HG
AIR TEMPERATURE           523.   DEG F    AIR TEMPERATURE           524.  DEG F
AIR VELOCITY            129.53 FT/SEC     AIR VELOCITY            131.20 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.339    "HG

AIR FLOW DATA: P-REF= 101.8 PSIA   DELTA P= 4.99 "HG    T-REF=  92. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       847.       HZ    VOLUMETRIC FLOW RATE  38.79 GAL/HR
FUEL PRESSURE AT F/M   564.6      PSIA    FUEL TEMP AT F/M         99.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    86.20 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              89.80 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 9.65  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    3.261 %     O2  16.000 %     CO    170.9 PPM      CHX        .0 PPM
 NO     40.8 PPM  NO2      16.1 PPM  NOX    56.9 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2        .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   8.61                   CHX=     .00
                  CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=     4.71

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .015928
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7372 %
   CHECK ON F/A RATIO- F/A = .015597 W/O O2. CALCULATED O2 = 16.444 %

SMOKE INDEX:   41.93
SALTZMAN NOX =  68.1              PPM     E.I. = 5.64
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Figure 244. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative 100% Power.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 43, TEST SERIES 52, READING #    785
T 63 FINAL DESIGN - PRECHAMBER LINER - RUNNING ON PRESSURE ATOMIZER
TEST DATE:  6-15-72                    READING WAS TAKEN AT 1920155 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.877 LB/SEC    AVG BURNER INLET TEMP    286. DEG F
AVG BURNER INLET PRES  43.7    PSIA      AVG BURNER OUTLET TEMP   376. DEG F
AVG BURNER DELTA P      5.80    "HG      PRESSURE LOSS            5.62 %
OVERALL F/A RATIO     .00110  (F/F)     FUEL FLOW RATE           7.45 LB/HR
AIR LOAD FACTOR         1.1884           PATTERN FACTOR          .33868
HOT HOT SPOT: # 27 #  433.  DEG F       MAX BOT / AVG BOT       1.0719
FUEL INLET TEMPERATURE 104.  DEG F      FUEL INLET PRESSURE       61.0  PSIA
HEAT LOADING PARAMETER  .33022E+06 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  384.  6  368. 15  376. 19  369. 24  381. 27  403. 30  387.
ANNULUS 2   4  365.  7  363. 16  375. 21  372. 25  378. 34  383. 37  389.
ANNULUS 3   5  356. 14  386. 17  367. 22  368. 26  374. 33  384. 39  380.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          43.71   PSIA    TOTAL PRESSURE          43.73   PSIA
STATIC PRESSURE         43.45   PSIA    STATIC PRESSURE         43.44   PSIA
VELOCITY DELTA P          .53    "HG    VELOCITY DELTA P          .59    "HG
AIR TEMPERATURE         296.  DEG F     AIR TEMPERATURE         298.  DEG F
AIR VELOCITY          124.81 FT/SEC     AIR VELOCITY          131.80 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.020    "HG

AIR FLOW DATA: P-REF= 145.3 PSIA   DELTA P= 1.59 "HG   T-REF=  83. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        20.      HZ    VOLUMETRIC FLOW RATE    1.20 GAL/HR
FUEL PRESSURE AT F/M   311.7    PSIA    FUEL TEMP AT F/M          90.  DEG F

             ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    41.26 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             42.98 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.99  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX = X                    PPM
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Figure 245. Final Prechamber Liner Initial Design on Pressure Atomizer Injection at Nonregenerative Lean Blow Out.

TABLE LXXIV. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, (2) FINAL DESIGN PRECHAMBER LINER WITH WALL FUEL FILM INJECTION, AND (3) FINAL DESIGN PRECHAMBER LINER WITH STANDARD PRESSURE ATOMIZING INJECTION.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	892.7	651.5	495.5	382.9	210.1	74.7
H/C, (ppm)	100.0	37.0	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.1	45.8	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.19
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Final Design Prechamber-Wall Fuel Film						
A. Emissions						
CO, (ppm)	430.3	242.5	194.1	179.2	166.8	116.2
H/C, (ppm)	6.5	.6	.0	.5	1.1	1.0
NO_x, (On-Line, NDIR & NDUV) (ppm)	19.5	25.2	31.6	42.6	51.1	94.9
NO_x, (Saltzman) (ppm)	19.3	26.2	32.5	40.7	52.1	81.1*
Smoke Number	2.47	1.78	2.89	10.47	26.03	61.29
B. Pressure Loss (%)	5.90	5.83	5.86	5.81	5.27	4.75
C. Temp. Profile (T_{max}/T_{avg})	1.248	1.258	1.200	1.256	1.226	1.223
III. Final Design Prechamber-Pressure Atomizer						
A. Emissions						
CO, (ppm)	74.6	123.7	141.0	170.9	191.9	170.9
H/C, (ppm)	.4	.3	.4	.6	.0	.0
NO_x, (On-Line, NDIR & NDUV) (ppm)	14.7	26.7	36.9	45.2	50.3	56.9
NO_x, (Saltzman) (ppm)	-	31.3	42.8	50.6	57.1	68.1
Smoke Number	-	0.00	0.00	4.90	14.98	41.93
B. Pressure Loss (%)	6.11	6.49	6.25	6.09	5.83	5.30
C. Temp. Profile (T_{max}/T_{avg})	1.155	1.128	1.127	1.111	1.132	1.226

*Diluted Sample - Low Reading

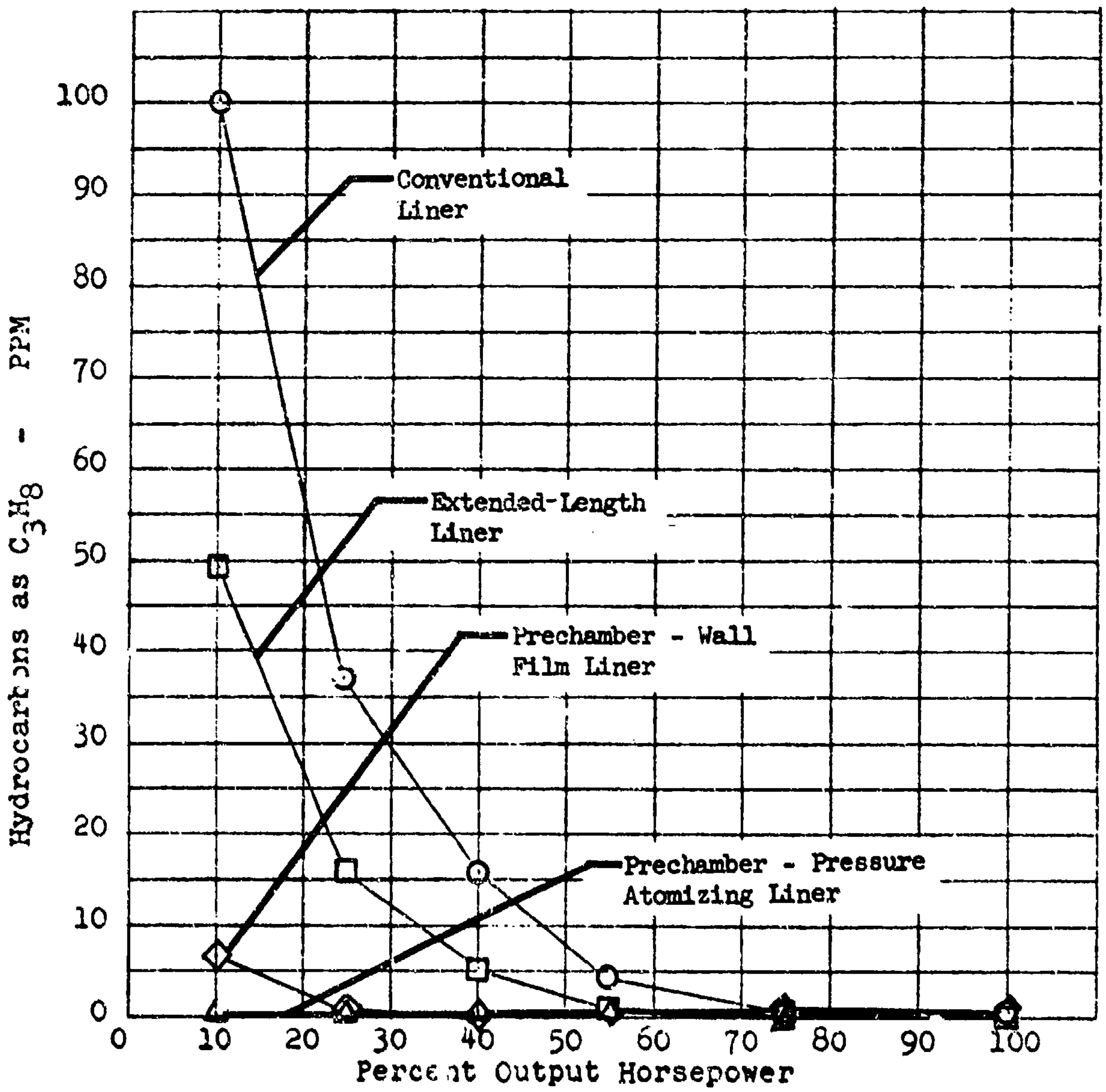

Figure 246. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Prechamber Final Design Combustor and T63 Baseline Combustors.

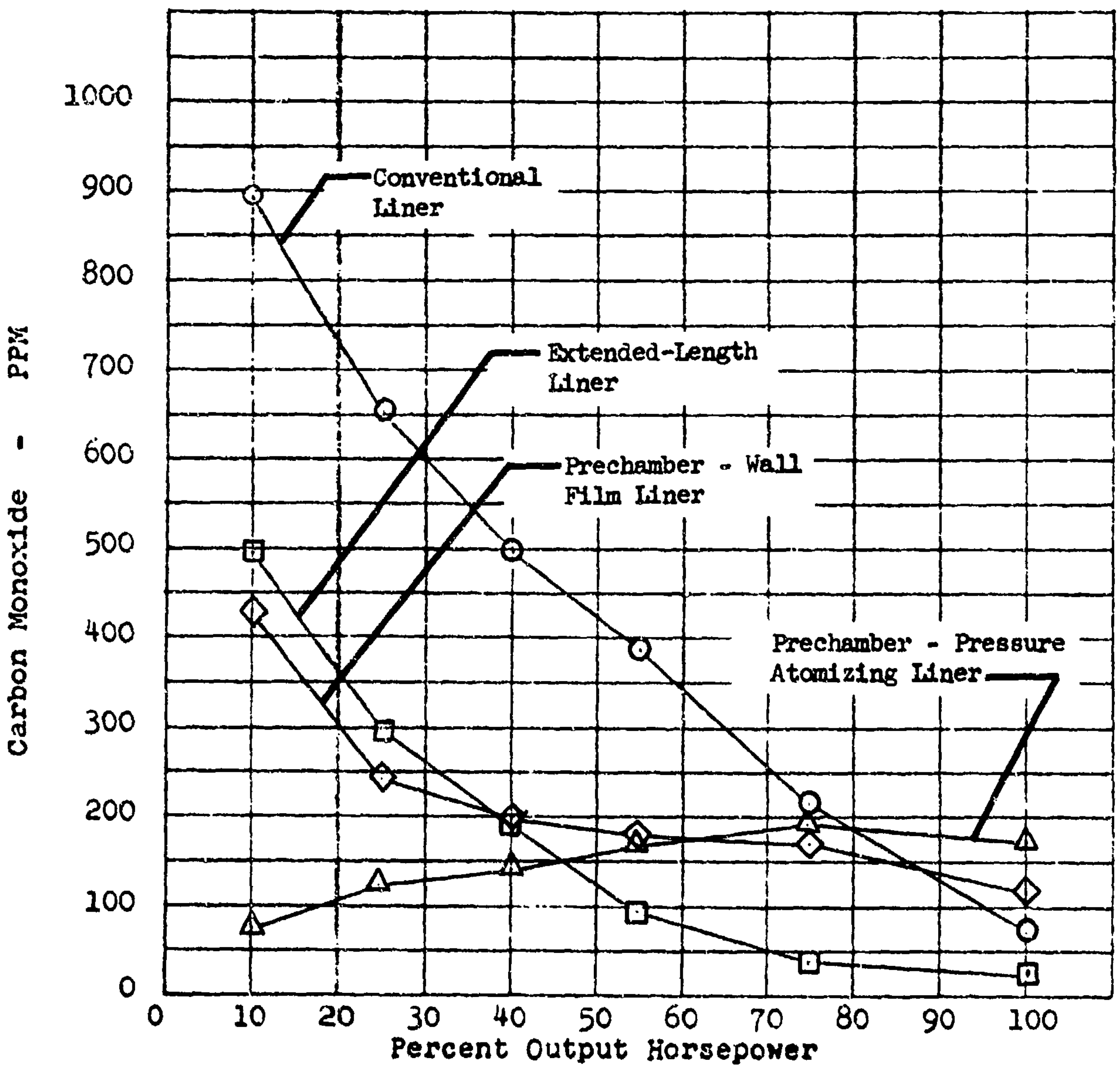

Figure 247. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Prechamber Final Design Combustor and T63 Baseline Combustors.

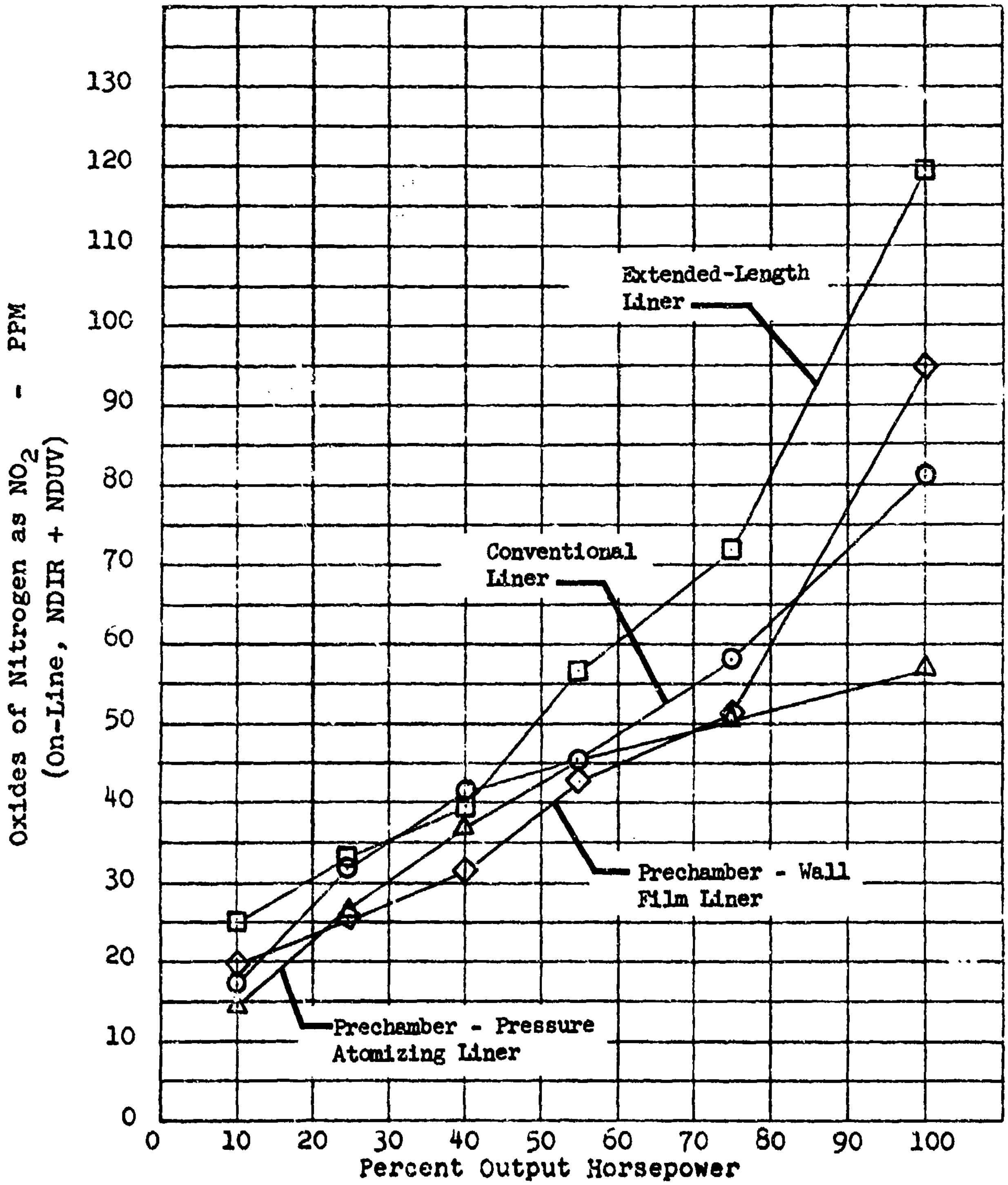

Figure 248. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber Final Design Combustor and T63 Baseline Combustors.

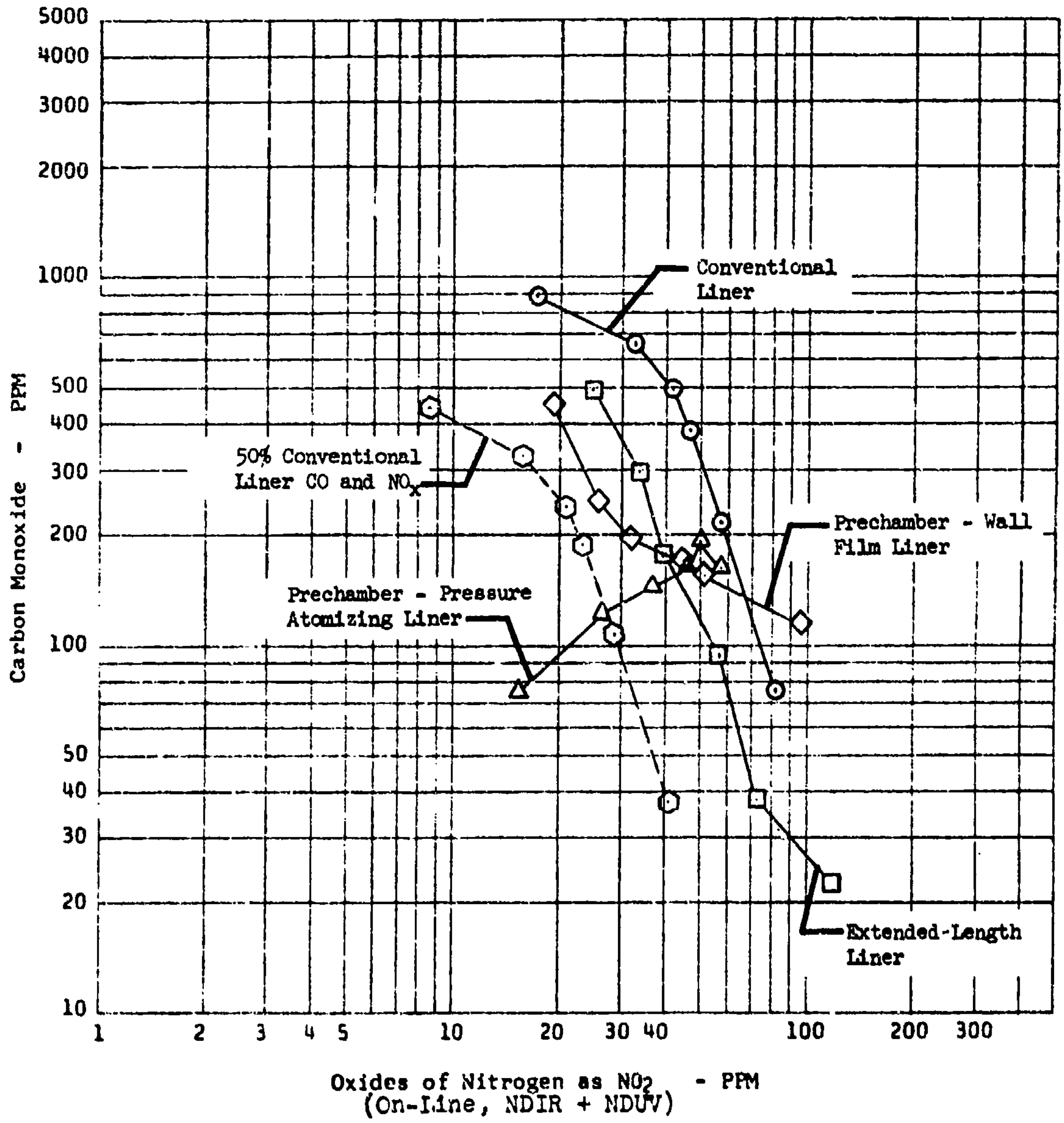

Figure 249. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber Final Design Combustor and T63 Baseline Combustors.

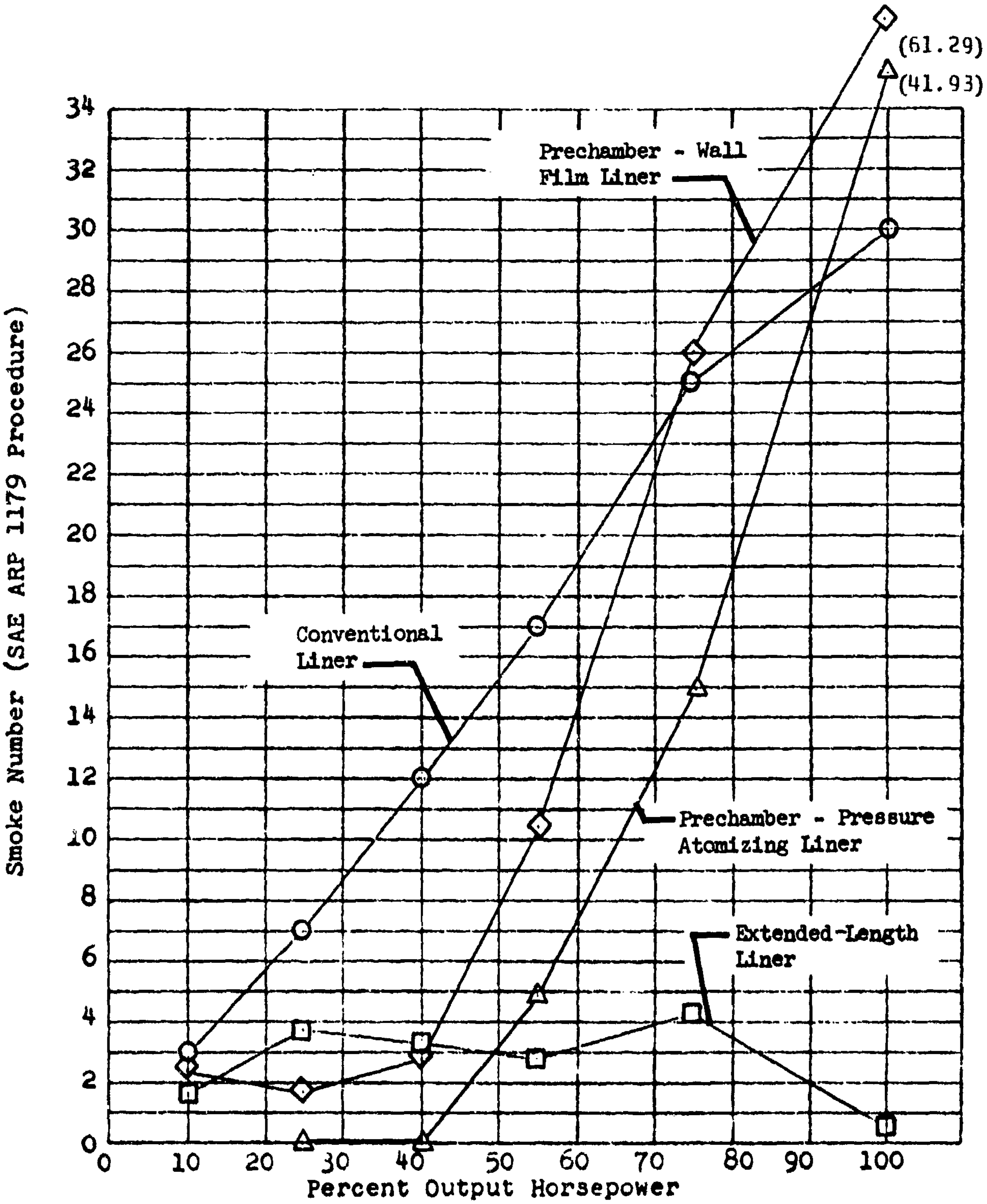

Figure 250. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Prechamber Final Design Combustor and T63 Baseline Combustors.

Comparing the performance of the Final Prechamber operating on the pressure atomizer nozzle with the Rich Premix/Swirl combustor tested in the preliminary test series, the emission performances were very similar. The wall fuel film operation, however, did not perform nearly as well as the preliminary version. For this operating mode, the richer reaction zone showed the anticipated effects of lowering the hydrocarbon concentrations, lowering the CO at idle, and increasing the NO_x. What was not obtained, however, were the low levels of CO at the higher power levels and the elimination of smoke. Overall, the pressure atomizer reduced the total emissions by 53% with no constituent increase. The wall fuel film mode reduced overall emissions by 44%, but allowed a 41% increase in particulates.

Exhaust temperature profiles are plotted in Figure 251. Except for 100% power conditions, the pressure atomizing mode of the "Prechamber" gave a satisfactory profile. However, the wall fuel film mode profile was high at all operating points.

Lean blowout from idle was determined to occur at a fuel-air ratio of 0.0062 for the "Wall Fuel Film Prechamber Liner", but when operating on the pressure atomizer, the combustor exhibited no lean blowout point. Fuel was reduced until the flow rate was too low to be accurately measured. Final data were taken at a fuel-air ratio giving only 80°F temperature rise. At this condition, the fuel was shut off.

Skin thermocouple temperature data are shown in Figures 252 and 253. With pressure atomization, the reaction zone appears to move downstream as more fuel is added. Using wall film vaporization, however, the reaction appears to maintain the same axial position regardless of fuel flow rates. It is clear that the vaporizer tube wall is significantly cooled by the vaporizing wall fuel film, as its temperature is always below the inlet temperature.

Modification "A"

Final Prechamber Modification "A" consisted of removing 1.5 inches of axial length from the vaporizer tube to permit more combustion gases to pass up the center of the vaporizer tube swirl vortex and increase the fuel vaporization rate. Also, a 1.50-inch long cylindrical section was added downstream of the dilution holes to allow more time for dilution mixing and thus improve the exhaust temperature profile.

The detailed acquisition data sheets for Prechamber Modification "A" are presented in Figures 254 through 258 for wall fuel film operation and in Figures 259 through 264 for pressure atomizing nozzle operation. The emission, pressure-loss, and temperature-profile data are summarized in Table LXXV. Pressure losses for the Prechamber combustor remained at 1% - 1.5% higher on the average than the Conventional T63 combustor pressure loss.

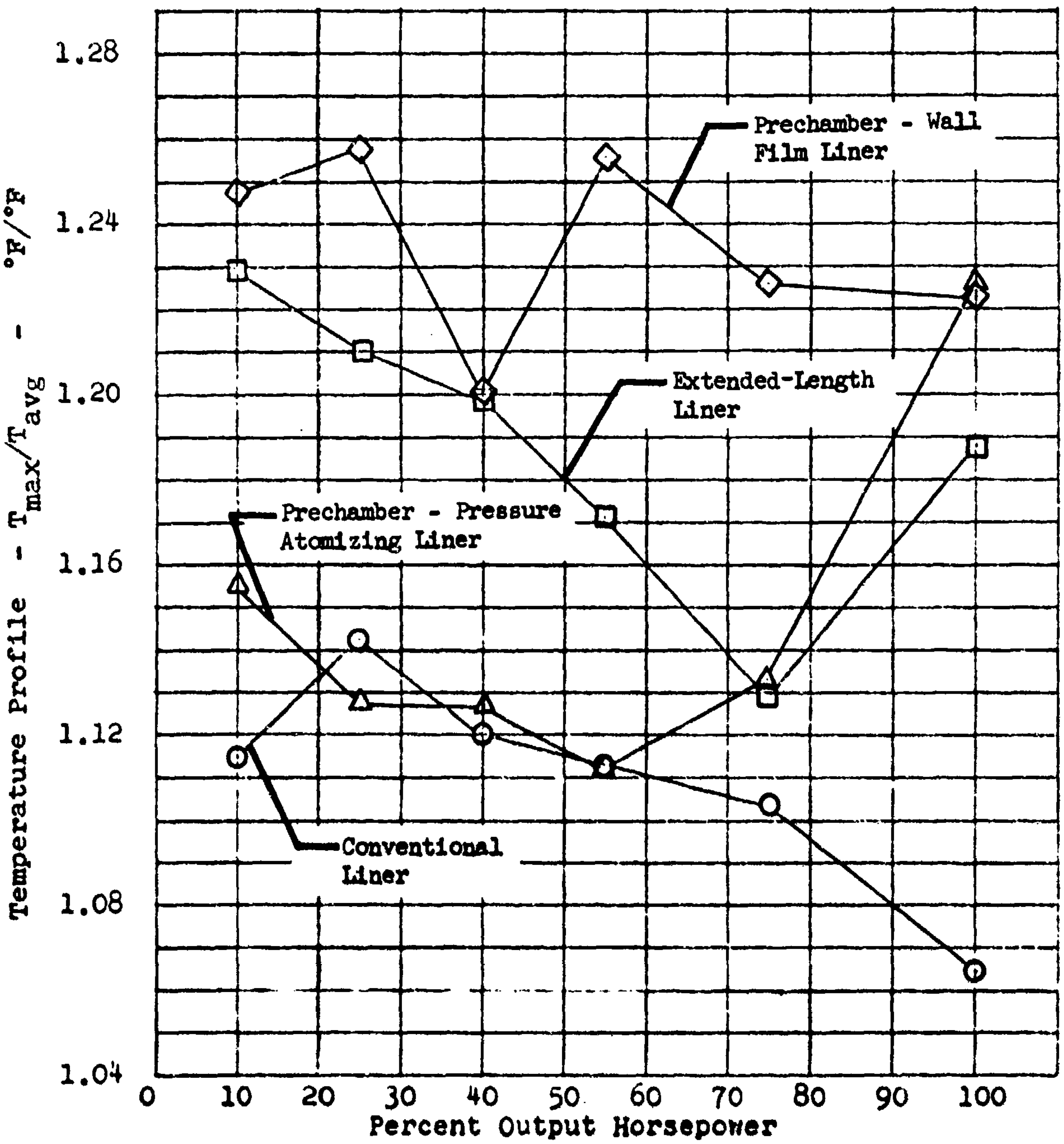

Figure 251. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Prechamber Final Design Combustor and T63 Baseline Combustors.

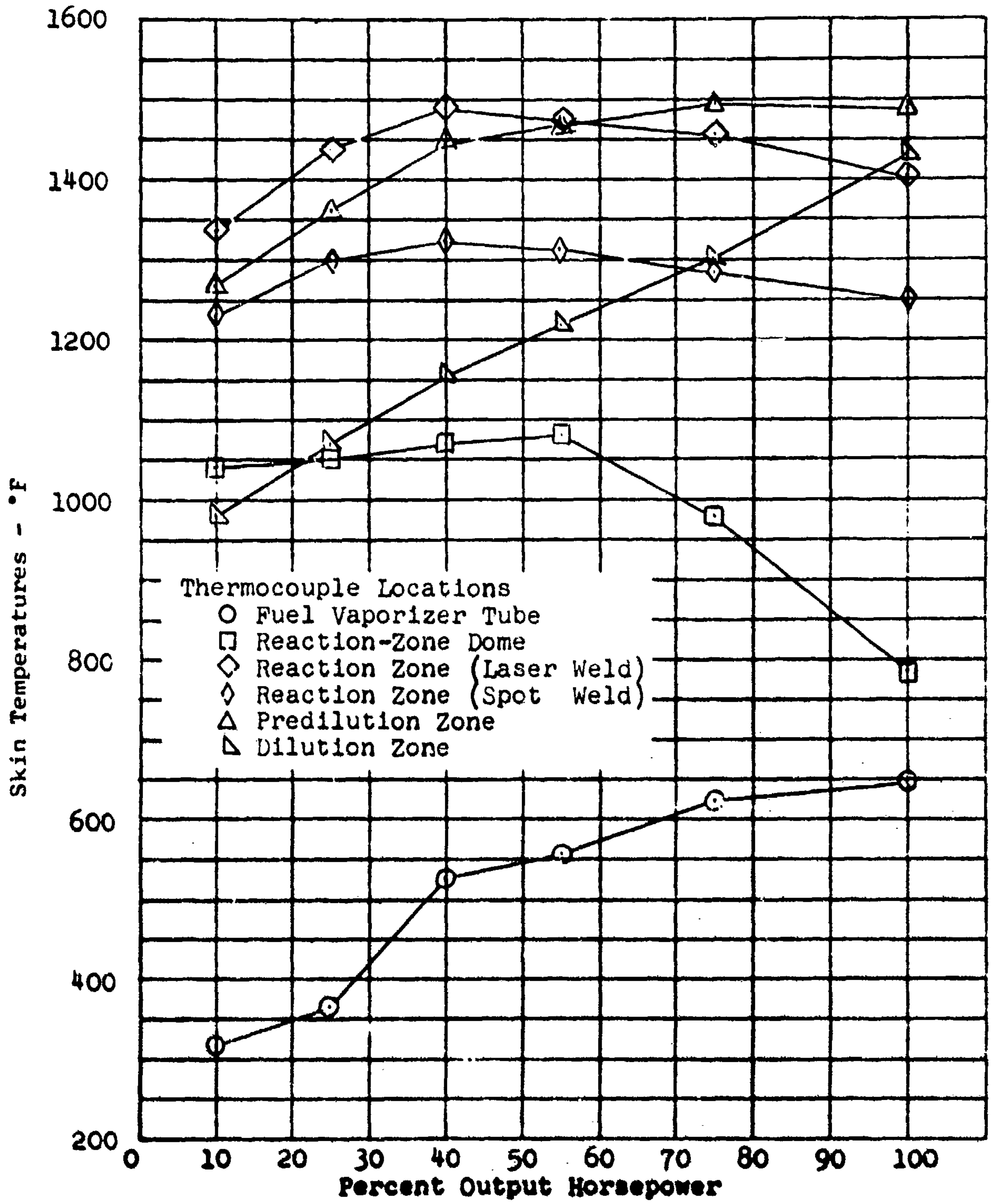

Figure 252. Nonregenerative T63-A-5A Combustor Combustor Skin Temperatures for Prechamber Final Design Combustor Operating on Pressure Atomizer Injection.

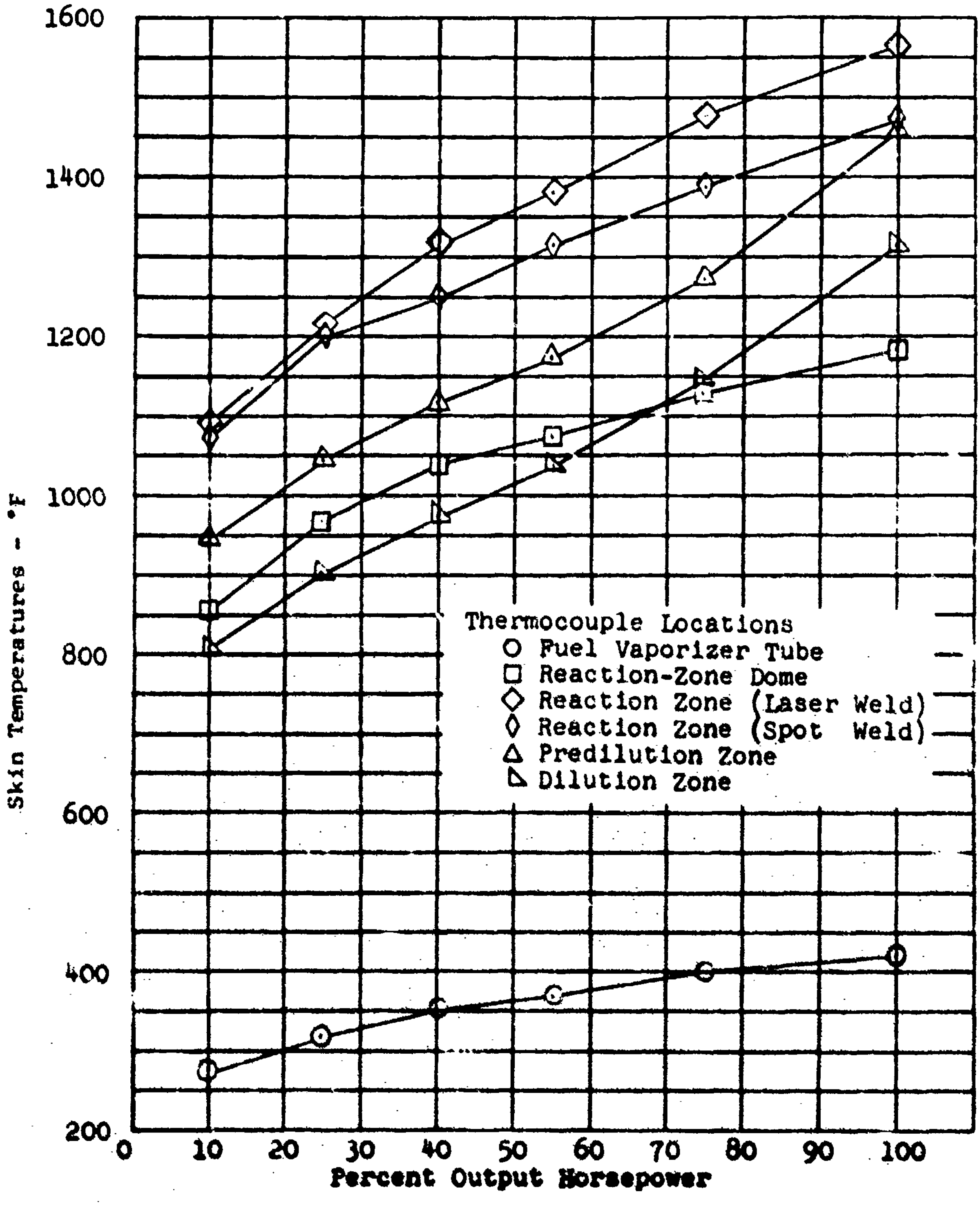

Figure 253. Nonregenerative T63-A-5A Combustor Combustor Skin Temperatures for Prechamber Final Design Combustor Operating on Wall Fuel Film Injection.

T63 COMBUSTOR EXPERIMENTS - RIG 8/U 56, TEST SERIES 65, READING # 794
T63 PRECHAMBER FINAL DESIGN, MOD "A" RUN STD. CYCLE ON WALL FILM NOZZLE
TEST DATE: 7-12-72 READING WAS TAKEN AT 1559: 2 HOURS

CYCLE POINT 1 10 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	1.896 LB/SEC	AVG BURNER INLET TEMP	300. DEG F
AVG BURNER INLET PRES	44.6 PSIA	AVG BURNER OUTLET TEMP	1070. DEG F
AVG BURNER DELTA P	5.43 "HG	PRESSURE LOSS	5.00 %
OVERALL F/A RATIO	.01086 (F/M)	FUEL FLOW RATE	74.10 LB/HR
AIR LOAD FACTOR	1.1723	PATTERN FACTOR	.30659
BOT HOT SPOT: # 25 = 1317. DEG F		MAX BOT / AVG BOT	1.2913
FUEL INLET TEMPERATURE	112. DEG F	FUEL INLET PRESSURE	56.4 PSIA

HEAT LOADING PARAMETER .28284E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	954.	6	1016.	15	1176.	19	1000.	24	1265.	27	1304.	36	824.
ANNULUS 2	4	1016.	7	1110.	16	1237.	21	1243.	25	1317.	34	809.	37	850.
ANNULUS 3	5	963.	14	1143.	17	1145.	22	1276.	26	1280.	35	723.	39	896.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	44.56 PSIA	TOTAL PRESSURE	44.59 PSIA
STATIC PRESSURE	44.28 PSIA	STATIC PRESSURE	44.33 PSIA
VELOCITY DELTA P	.56 "HG	VELOCITY DELTA P	.52 "HG
AIR TEMPERATURE	300. DEG F	AIR TEMPERATURE	300. DEG F
AIR VELOCITY	126.83 FT/SEC	AIR VELOCITY	123.06 FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.065 "HG

AIR FLOW DATA: P-REF= 104.9 PSIA DELTA P= 1.78 "HG T-REF= 107. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY 274. HZ VOLUMETRIC FLOW RATE 11.04 GAL/HR
FUEL PRESSURE AT F/M 177.7 PSIA FUEL TEMP AT F/M 92. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 41.91 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 43.04 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 5.30 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 1.841 % O2 18.750 % CO 162.7 PPM CHX 2.0 PPM
NO 12.7 PPM NO2 6.4 PPM NOX 19.1 PPM (NO(NDIR) + NO2(NDUV))
NO 20.6 PPM NO2 .0 PPM NOX 20.6 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 14.60 CHX= .41
CHEMILUMINESCENCE NOX= 3.04, NDIR + NDUV NOX= 2.82

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .008768
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.9241 %
CHECK ON F/A RATIO- F/A = .008981 W/O O2, CALCULATED O2 = 18.423 %

SMOKE INDEX: 2.25
SALTZMAN NOX = 17.8 PPM E.I. = 2.63

Figure 254. Final Prechamber Liner Modification "A" on Wall Fuel Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 65, READING #     795
T63 PRECHAMBER FINAL DESIGN, MOD "A"  RUN STD, CYCLE ON WALL FILM NOZZLE
TEST DATE:  7-12-72                        READING WAS TAKEN AT 1624:53 HOURS

CYCLE POINT  6                                          25 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW           2.215 LB/SEC    AVG BURNER INLET TEMP    352. DEG F
AVG BURNER INLET PRES    54.4    PSIA     AVG BURNER OUTLET TEMP 1202. DEG F
AVG BURNER DELTA P        6.33    "HG     PRESSURE LOSS              5.71 %
OVERALL F/A RATIO       .01202  (F/F)     FUEL FLOW RATE            95.08 LB/HR
AIR LOAD FACTOR          1.1605           PATTERN FACTOR           .33986
BOT HOT SPOT:  # 25 = 1491.  DEG F        MAX BOT / AVG BOT        1.2403
FUEL INLET TEMPERATURE 122.  DEG F        FUEL INLET PRESSURE       75.1  PSIA
HEAT LOADING PARAMETER  .29991E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1469.  6 1128. 15 1292. 19 1225. 24 1435. 27 1404. 36  929.
ANNULUS 2   4 1125.  7 1258. 16 1328. 21 1366. 25 1491. 34  929. 37  949.
ANNULUS 3   5 1058. 14 1236. 17 1237. 22 1414. 26 1436. 35  925. 39  992.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE            54.37   PSIA    TOTAL PRESSURE           54.42   PSIA
STATIC PRESSURE           54.11   PSIA    STATIC PRESSURE          53.99   PSIA
VELOCITY DELTA P            .53    "HG    VELOCITY DELTA P           .86    "HG
AIR TEMPERATURE            352.  DEG F    AIR TEMPERATURE           352.  DEG F
AIR VELOCITY            115.33 FT/SEC     AIR VELOCITY            147.91 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.101    "HG

AIR FLOW DATA: P-REF= 144.1 PSIA   DELTA P= 2.35 "HG   T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        354.      HZ    VOLUMETRIC FLOW RATE  15.47 GAL/HR
FUEL PRESSURE AT F/M   171.3     PSIA    FUEL TEMP AT F/M            94.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     51.20 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               53.60 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  6.28  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.010 %     O2  18.500 %      CO   150.7 PPM     CHX      2.6 PPM
 NO     16.9 PPM  NO2      8.1 PPM  NOX    25.0 PPM (NO(NDIR) + NO2(NDUV))
 NO     26.5 PPM  NO2      2.0 PPM  NOX    28.5 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12.92                    CHX=    .33
                  CHEMILUMINESCENCE NOX=   3.81,   NDIR + NDUV NOX=    3.34

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .009560
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.5731 %
   CHECK ON F/A RATIO- F/A = .009700 W/O O2, CALCULATED O2 = 18.187 %

SMOKE INDEX:  4.90
SALTZMAN NOX =  25.2              PPM          E.I. = 3.37
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Figure 255. Final Prechamber Liner Mod. "A" on Wall Fuel Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 65, READING #    798
T63 PRECHAMBER FINAL DESIGN, MOD "A"  RUN STD. CYCLE ON WALL FILM NOZZLE
TEST DATE: 7-12-72                    READING WAS TAKEN AT 1649:58 HOURS

CYCLE POINT  5                                        40 % POWER SETTING

                ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.533 LB/SEC    AVG BURNER INLET TEMP    397. DEG F
AVG BURNER INLET PRES  63.7    PSIA      AVG BURNER OUTLET TEMP 1303. DEG F
AVG BURNER DELTA P       7.50    "HG     PRESSURE LOSS             5.78 %
OVERALL F/A RATIO       .01311  (F/M)    FUEL FLOW RATE          119.58 LB/HR
AIR LOAD FACTOR         1.1639           PATTERN FACTOR           .31719
BOT HOT SPOT: # 27 = 1598.  DEG F        MAX BOT / AVG BOT        1.2285
FUEL INLET TEMPERATURE 133.  DEG F       FUEL INLET PRESSURE       93.6  PSIA
HEAT LOADING PARAMETER  .31939E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
         ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1154.  6 1224. 15 1485. 19 1336. 24 1525. 27 1598. 36 1001.
ANNULUS 2  4 1238.  ? 1333. 16 1469. 21 1507. 25 1575. 34  992. 37 1020.
ANNULUS 3  5 1169. 14 1460. 17 1396. 22 1502. 26 1550. 35  899. 39 1075.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           63.67   PSIA    TOTAL PRESSURE          63.74   PSIA
STATIC PRESSURE          63.17   PSIA    STATIC PRESSURE         63.38   PSIA
VELOCITY DELTA P          1.01    "HG    VELOCITY DELTA P          .73    "HG
AIR TEMPERATURE          397.   DEG F    AIR TEMPERATURE         397.   DEG F
AIR VELOCITY            151.04 FT/SEC    AIR VELOCITY            128.87 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.146    "HG

AIR FLOW DATA: P-REF= 103.1 PSIA   DELTA P= 3.00 "HG   T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       441.      HZ    VOLUMETRIC FLOW RATE  10.31 GAL/HR
FUEL PRESSURE AT F/M   105.0     PSIA    FUEL TEMP AT F/M        90.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE      60.82 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               62.60 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  7.43  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2    2.107 %     O2   18.200 %    CO    156.7 PPM     CHX     2.7 PPM
 NO     29.4 PPM  NO2      0.0 PPM  NOX    29.4 PPM (NO(NDIR) + NO2(NDUV))
 NO     30.2 PPM  NO2       .0 PPM  NOX    30.2 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX  LB/1000 LB FUEL: CO=  11.71                 CHX=     .38
                 CHEMILUMINESCENCE NOX=   4.01,   NDIR + NDUV NOX=   3.86

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010000
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8003 %
  CHECK ON F/A RATIO- F/A = .010100 W/O O2, CALCULATED O2 = 18.000 %

SMOKE INDEX: 6.20
SALTZMAN NOX = 31.5            PPM      E.I. = 3.87
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Figure 256. Final Prechamber Liner Mod. "A" on Wall Fuel Injection at Nonregenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 65, READING #    797
T63 PRECHAMBER FINAL DESIGN, MOD "A"  RUN STD. CYCLE ON WALL FILM NOZZLE
TEST DATE: 7-12-72                     READING WAS TAKEN AT 173024 HOURS

CYCLE POINT  4                                        55 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.720 LB/SEC    AVG BURNER INLET TEMP   430. DEG F
AVG BURNER INLET PRES  71.0    PSIA      AVG BURNER OUTLET TEMP 1431. DEG F
AVG BURNER DELTA P       8.10    "HG     PRESSURE LOSS              5.61 %
OVERALL F/A RATIO      .01461  (F/F)     FUEL FLOW RATE          143.03 LB/HR
AIR LOAD FACTOR         1.1427           PATTERN FACTOR           .33806
BOT HOT SPOT: # 25 = 1769.  DEG F        MAX BOT / AVG BOT        1.2364
FUEL INLET TEMPERATURE 144.  DEG F       FUEL INLET PRESSURE      113.3  PSIA
HEAT LOADING PARAMETER   .34268E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1320.  6 1329. 15 1516. 19 1450. 24 1667. 27 1752. 36 1069.
ANNULUS 2   4 1365.  7 1512. 16 1582. 21 1675. 25 1769. 34 1090. 37 1102.
ANNULUS 3   5 1279. 14 1483. 17 1511. 22 1646. 26 1765. 35  984. 39 1151.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          71.02    PSIA    TOTAL PRESSURE          71.02   PSIA
STATIC PRESSURE         70.55    PSIA    STATIC PRESSURE         70.50   PSIA
VELOCITY DELTA P          .87    "HG     VELOCITY DELTA P          .88   "HG
AIR TEMPERATURE          430.  DEG F     AIR TEMPERATURE          430.  DEG F
AIR VELOCITY           135.12 FT/SEC     AIR VELOCITY           136.77 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.001   "HG

AIR FLOW DATA: P-REF= 102.0 PSIA   DELTA P= 3.57 "HG   T-REF= 102. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       520.     HZ     VOLUMETRIC FLOW RATE   23.11 GAL/HR
FUEL PRESSURE AT F/M   160.0    PSIA     FUEL TEMP AT F/M          97.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     67.04 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              69.05 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 8.10 "HG  (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    2.352 %     O2   17.600 %     CO    100.0 PPM     CHX       .0 PPM
NO      20.7 PPM  NO2     12.3 PPM  NOX     39.1 PPM (NO(NDIR) + NO2(NDUV))
NO      52.9 PPM  NO2      1.0 PPM  NOX     53.8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.34                  CHX=     .00
                  CHEMILUMINESCENCE NOX=   5.94,   NDIR + NDUV NOX=    4.31

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .011380
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6230 %
   CHECK ON F/A RATIO- F/A = .011322 W/O O2, CALCULATED O2 = 17.700 %

SMOKE INDEX:  .43
SALTZMAN NOX =  42.4              PPM        E.I.: 4.67
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Figure 257. Final Prechamber Liner Mod. "A" on Wall Fuel Injection at Nonregenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 65, READING #    798
T63 PRECHAMBER FINAL DESIGN, MOD "A"  RUN STD. CYCLE ON WALL FILM NOZZLE
TEST DATE: 7-12-72                   READING WAS TAKEN AT 1757:40 HOURS

CYCLE POINT  3                                        75 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.992 LB/SEC    AVG BURNER INLET TEMP   472. DEG F
AVG BURNER INLET PRES  80.4    PSIA     AVG BURNER OUTLET TEMP 1570. DEG F
AVG BURNER DELTA P      8.81    "HG     PRESSURE LOSS             5.39 %
OVERALL F/A RATIO     .01647  (F/M)     FUEL FLOW RATE          177.41 LB/HR
AIR LOAD FACTOR       1.1366            PATTERN FACTOR          .44510
BOT HOT SPOT:  # 26 = 2070.  DEG F      MAX BOT / AVG BOT       1.3119
FUEL INLET TEMPERATURE 151.  DEG F      FUEL INLET PRESSURE     145.9  PSIA
HEAT LOADING PARAMETER  .37552E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1366.  6 1476. 15 1694. 19 1577. 24 1829. 27 1965. 36 1223.
ANNULUS 2   4 1493.  7 1654. 16 1748. 21 1768. 25 1970. 34 1245. 37 1233.
ANNULUS 3   5 1521. 14 1771. 17 1449. 22 1655. 26 2070. 35 1228. 39 1183.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE         80.33    PSIA    TOTAL PRESSURE          80.43   PSIA
STATIC PRESSURE        79.89    PSIA    STATIC PRESSURE         80.03   PSIA
VELOCITY DELTA P        .90     "HG     VELOCITY DELTA P         .81    "HG
AIR TEMPERATURE        472.   DEG F     AIR TEMPERATURE         472.  DEG F
AIR VELOCITY          133.28 FT/SEC     AIR VELOCITY          125.95 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.196   "HG

AIR FLOW DATA: P-REF= 102.3 PSIA   DELTA P= 4.33 "HG    T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      657.      HZ    VOLUMETRIC FLOW RATE  28.68 GAL/HR
FUEL PRESSURE AT F/M  261.9    PSIA     FUEL TEMP AT F/M         97.  DEG F

             ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    76.05 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              79.08 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 8.72  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2    2.550 %     O2  17.250 %     CO   166.8 PPM    CHX      2.3 PPM
 NO     33.7 PPM  NO2     16.1 PPM  NOX    49.9 PPM (NO(NDIR) + NO2(NDUV))
 NO     78.7 PPM  NO2      3.0 PPM  NOX    81.8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   9.96                 CHX=    .22
              CHEMILUMINESCENCE NOX=   8.02,    NDIR + NDUV NOX=   4.89

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .012364
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6206 %
   CHECK ON F/A RATIO- F/A = .012250 W/O O2. CALCULATED O2 = 17.431 %

SMOKE INDEX: 25.0
SALTZMAN NOX = X                    PPM
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Figure 258. Final Prechamber Liner Modification "A" on Wall Fuel Injection at Nonregenerative 75% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 66, READING #    799
T63 PRECHAMBER FINAL DESIGN, MOD "A"   RUN STD, CYCLE ON PRESSURE NOZZLE
TEST DATE: 7-13-72                     READING WAS TAKEN AT 1359: 5 HOURS

CYCLE POINT  1                                         10 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.874 LB/SEC    AVG BURNER INLET TEMP   300. DEG F
AVG BURNER INLET PRES  44.7   PSIA      AVG BURNER OUTLET TEMP 1068. DEG F
AVG BURNER DELTA P      5.34    "HG     PRESSURE LOSS             5.86 %
OVERALL F/A RATIO     .01082  (F/M)     FUEL FLOW RATE           73.01 LB/HR
AIR LOAD FACTOR        1.1554           PATTERN FACTOR          .18483
BOT HOT SPOTS  # 27 = 1209.  DEG F      MAX BOT / AVG BOT      1.1329
FUEL INLET TEMPERATURE 115.  DEG F      FUEL INLET PRESSURE     207.0  PSIA
HEAT LOADING PARAMETER  .27794E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  984.  6 1030. 15 1144. 19 1081. 24 1168. 27 1209. 36  874.
ANNULUS 2   4 1036.  7 1153. 16 1196. 21 1185. 25 1199. 34  892. 37  916.
ANNULUS 3   5 1027. 14 1143. 17 1132. 22 1125. 26 1152. 35  855. 39  916.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE            44.68    PSIA    TOTAL PRESSURE          44.71   PSIA
STATIC PRESSURE           44.39    PSIA    STATIC PRESSURE         44.43   PSIA
VELOCITY DELTA P            .59     "HG    VELOCITY DELTA P          .57    "HG
AIR TEMPERATURE            300.   DEG F    AIR TEMPERATURE          300.  DEG F
AIR VELOCITY             130.61 FT/SEC     AIR VELOCITY           128.44 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]           -.074    "HG

AIR FLOW DATA: P-REF= 105.0 PSIA   DELTA P= 1.66 "HG   T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      270.     HZ     VOLUMETRIC FLOW RATE  11.77 GAL/HR
FUEL PRESSURE AT F/M  272.1    PSIA     FUEL TEMP AT F/M         93.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   42.07 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            43.93 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               5.30  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    1.961 %     O2  16.600 %     CO     83.6 PPM     CHX       .7 PPM
 NO     13.4 PPM  NO2      5.6 PPM  NOX    19.0 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   7.57                 CHX=     .10
                  CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   2.82

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:      .009286
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7793 %
   CHECK ON F/A RATIO- F/A = .009433 W/O O2, CALCULATED O2 = 18.262 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 12.0              PPM    E.I. = 1.78
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Figure 259. Final Prechamber Liner Modification "A" on Pressure Atomizer Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 86, READING #    800
T63 PRECHAMBER FINAL DESIGN, MOD "A"   RUN STD, CYCLE ON PRESSURE NOZZLE
TEST DATE: 7-13-72                       READING WAS TAKEN AT 1423: 1 HOURS

CYCLE POINT  6                                          25 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.150 LB/SEC    AVG BURNER INLET TEMP   350. DEG F
AVG BURNER INLET PRES  54.0   PSIA      AVG BURNER OUTLET TEMP 1205. DEG F
AVG BURNER DELTA P      6.20    "HG     PRESSURE LOSS             5.64 %
OVERALL F/A RATIO      .01230  (F/H)    FUEL FLOW RATE           95.60 LB/HR
AIR LOAD FACTOR        1.1374           PATTERN FACTOR          .19036
BOT HOT SPOT:  # 21 = 1375.  DEG F      MAX BOT / AVG BOT      1.1400
FUEL INLET TEMPERATURE 126.  DEG F      FUEL INLET PRESSURE    239.5  PSIA
HEAT LOADING PARAMETER  .30134E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1107.   6 1142. 15 1320. 10 1216. 24 1336. 27 1352. 36  901.
ANNULUS 2   4 1146.   7 1273. 16 1357. 21 1375. 25 1353. 34 1014. 37 1020.
ANNULUS 3   5 1157.  14 1294. 17 1262. 22 1281. 26 1317. 35  950. 39 1054.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           53.98   PSIA    TOTAL PRESSURE          53.97   PSIA
STATIC PRESSURE          53.65   PSIA    STATIC PRESSURE         53.71   PSIA
VELOCITY DELTA P           .66    "HG    VELOCITY DELTA P          .54    "HG
AIR TEMPERATURE           349.  DEG F    AIR TEMPERATURE          350.  DEG F
AIR VELOCITY            129.66 FT/SEC    AIR VELOCITY           117.61 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]            .000    "HG

AIR FLOW DATA: P-REF= 103.9 PSIA    DELTA P= 2.23 "HG    T-REF= 107. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        353.       HZ    VOLUMETRIC FLOW RATE  15.43 GAL/HR
FUEL PRESSURE AT F/M    264.4     PSIA    FUEL TEMP AT F/M         95.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    50.93 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             53.24 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.20  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2   2.156 %     O2  18.400 %      CO    116.2 PPM      CHX       .2 PPM
 NO     18.3 PPM  NO2      4.8 PPM  NOX    23.1 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   9.24                  CHX=     .03
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    3.02

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .010171
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7349 %
   CHECK ON F/A RATIO- F/A = .010368 W/O O2, CALCULATED O2 = 17.989 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 24.0                 PPM       E.I. = 3.14
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Figure 260. Final Prechamber Liner Modification "A" on Pressure Atomizer Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 66, READING #    001
T63 PRECHAMBER FINAL DESIGN, MOD "A"   RUN STD. CYCLE ON PRESSURE NOZZLE
TEST DATE: 7-13-72                      READING WAS TAKEN AT 1442:34 HOURS

CYCLE POINT  5                                        40 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.491 LB/SEC    AVG BURNER INLET TEMP   398. DEG F
AVG BURNER INLET PRES  63.1   PSIA      AVG BURNER OUTLET TEMP 1307. DEG F
AVG BURNER DELTA P      7.41   "HG      PRESSURE LOSS             5.76 %
OVERALL F/A RATIO     .01312  (F/M)     FUEL FLOW RATE          117.62 LB/HR
AIR LOAD FACTOR        1.1554           PATTERN FACTOR          .22153
BOT HOT SPOT:  # 21 = 1508.  DEG F      MAX BOT / AVG BOT       1.1540
FUEL INLET TEMPERATURE 133.  DEG F      FUEL INLET PRESSURE     269.3  PSIA
HEAT LOADING PARAMETER  .31694E+07 BTU/HOUR/ATM/CUBIC FOOT

               **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1221.  6 1210. 15 1404. 19 1364. 24 1430. 27 1440. 36 1047.
ANNULUS 2   4 1264.  7 1352. 16 1457. 21 1508. 25 1462. 34 1080. 37 1100.
ANNULUS 3   5 1265. 14 1437. 17 1397. 22 1387. 26 1441. 35 1085. 39 1152.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           63.16   PSIA   TOTAL PRESSURE          63.13   PSIA
STATIC PRESSURE          62.89   PSIA   STATIC PRESSURE         62.76   PSIA
VELOCITY DELTA P           .54    "HG   VELOCITY DELTA P          .75    "HG
AIR TEMPERATURE          398.  DEG F    AIR TEMPERATURE         398.  DEG F
AIR VELOCITY           111.83 FT/SEC    AIR VELOCITY          131.61 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          .055    "HG

AIR FLOW DATA: P-REF= 103.3 PSIA   DELTA P= 2.99 "HG   T-REF= 107. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       434.      HZ   VOLUMETRIC FLOW RATE  19.00 GAL/HR
FUEL PRESSURE AT F/M   372.2    PSIA    FUEL TEMP AT F/M           97.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   59.50 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            62.13 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               7.44  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2   2.303 %     O2  18.100 %     CO   135.2 PPM     CHX      .7 PPM
 NO    24.6 PPM  NO2      8.1 PPM  NOX    32.7 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.10                 CHX=    .09
                 CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=   4.01

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .010910
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7016 %
   CHECK ON F/A RATIO= F/A = .011073 W/O O2, CALCULATED O2 = 17.702 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 35.7                PPM       E.I. = 4.38
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Figure 261. Final Prechamber Liner Modification "A" on Pressure Atomizer Injection at Nonregenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 66, READING #    802
T63 PRECHAMBER FINAL DESIGN, MOD "A"   RUN STD, CYCLE ON PRESSURE NOZZLE
TEST DATE: 7-13-72                     READING WAS TAKEN AT 1509: 7 HOURS

CYCLE POINT  4                                       55 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.813 LB/SEC   AVG BURNER INLET TEMP   431. DEG F
AVG BURNER INLET PRES  71.4    PSIA     AVG BURNER OUTLET TEMP 1422. DEG F
AVG BURNER DELTA P       8.48    "HG    PRESSURE LOSS            5.83 %
OVERALL F/A RATIO      .01438  (F/M)    FUEL FLOW RATE         145.62 LB/HR
AIR LOAD FACTOR         1.1761          PATTERN FACTOR         .21595
BOT HOT SPOT:  # 21 = 1636.  DEG F      MAX BOT / AVG BOT      1.1505
FUEL INLET TEMPERATURE 142.  DEG F      FUEL INLET PRESSURE    316.8   PSIA
HEAT LOADING PARAMETER  .34708E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1312.  6 1320. 15 1518. 19 1508. 24 1551. 27 1591. 36 1127.
ANNULUS 2   4 1376.  7 1472. 16 1594. 21 1636. 25 1602. 34 1150. 37 1181.
ANNULUS 3   5 1378. 14 1509. 17 1550. 22 1538. 26 1595. 35 1101. 39 1261.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          71.35    PSIA    TOTAL PRESSURE          71.41    PSIA
STATIC PRESSURE         70.89    PSIA    STATIC PRESSURE         71.01    PSIA
VELOCITY DELTA P          .93     "HG    VELOCITY DELTA P          .82     "HG
AIR TEMPERATURE         431.   DEG F     AIR TEMPERATURE         431.   DEG F
AIR VELOCITY           140.56 FT/SEC     AIR VELOCITY           131.94 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.119     "HG

AIR FLOW DATA: P-REF= 102.7 PSIA   DELTA P= 3.85 "HG   T-REF= 107. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       538.      HZ    VOLUMETRIC FLOW RATE  23.55 GAL/HR
FUEL PRESSURE AT F/M   439.7     PSIA    FUEL TEMP AT F/M         90.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   67.22 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            70.14 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               8.42  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.420 %      O2  17.700 %      CO   166.8 PPM     CHX       .1 PPM
 NO     28.1 PPM   NO2     10.6 PPM   NOX    38.7 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM   NO2       .0 PPM   NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.30                  CHX=     .01
                  CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=   4.34

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .011619
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6632 %
   CHECK ON F/A RATIO= F/A = .011670 W/O O2, CALCULATED O2 = 17.607 %

SMOKE INDEX: 2.95
SALTZMAN NOX = 46.6               PPM          E.I. = 5.23
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Figure 262. Final Prechamber Liner Modification "A" on Pressure Atomizer Injection at Nonregenerative 55% Power.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 66, READING # 803
T63 PRECHAMBER FINAL DESIGN, MOD "A" RUN STD. CYCLE ON PRESSURE NOZZLE
TEST DATE: 7-13-72 READING WAS TAKEN AT 1534:32 HOURS

CYCLE POINT 3 75 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.973 LB/SEC	AVG BURNER INLET TEMP	472. DEG F
AVG BURNER INLET PRES	80.4 PSIA	AVG BURNER OUTLET TEMP	1616. DEG F
AVG BURNER DELTA P	9.26 "HG	PRESSURE LOSS	5.66 %
OVERALL F/A RATIO	.01677 (F/M)	FUEL FLOW RATE	179.52 LB/HR
AIR LOAD FACTOR	1.1285	PATTERN FACTOR	.24832
BOT HOT SPOT: # 21 = 1891.	DEG F	MAX BOT / AVG BOT	1.1702
FUEL INLET TEMPERATURE 158.	DEG F	FUEL INLET PRESSURE	391.6 PSIA

HEAT LOADING PARAMETER .37998E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1472.	6	1466.	15	1711.	19	1675.	24	1824.	27	1793.	36	1269.
ANNULUS 2	4	1539.	7	1673.	16	1774.	21	1891.	25	1840.	34	1312.	37	1343.
ANNULUS 3	5	1525.	14	1786.	17	1717.	22	1837.	26	1839.	35	1248.	39	1404.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	80.38 PSIA	TOTAL PRESSURE	80.56 PSIA
STATIC PRESSURE	79.77 PSIA	STATIC PRESSURE	80.11 PSIA
VELOCITY DELTA P	1.07 "HG	VELOCITY DELTA P	.80 "HG
AIR TEMPERATURE	471. DEG F	AIR TEMPERATURE	472. DEG F
AIR VELOCITY	145.32 FT/SEC	AIR VELOCITY	124.96 FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.403 "HG

AIR FLOW DATA: P-REF= 102.1 PSIA DELTA P= 4.32 "HG T-REF= 106. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	866. HZ	VOLUMETRIC FLOW RATE	29.86 GAL/HR
FUEL PRESSURE AT F/M	516.9 PSIA	FUEL TEMP AT F/M	101. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 75.85 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 79.22 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 9.86 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 2.881 % O2 17.308 % CO 181.3 PPM CHX .1 PPM
NO 28.8 PPM NO2 19.3 PPM NOX 48.1 PPM (NO(NDIR) + NO2(NDUV))
NO .0 PPM NO2 .0 PPM NOX .0 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 10.63 CHX= .01
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 4.63

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .013380
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.6885 %
CHECK ON F/A RATIO- F/A = .013443 W/O O2, CALCULATED O2 = 17.083 %

SMOKE INDEX: 11.2
SALTZMAN NOX = 62.5 PPM E.I. = 6.02

Figure 263. Final Prechamber Liner Modification "A" on Pressure Atomizer Injection at Nonregenerative 75% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 56, TEST SERIES 66, READING #     804
T63 PRECHAMBER FINAL DESIGN, MOD "A"   RUN STD, CYCLE ON PRESSURE NOZZLE
TEST DATE:  7-13-72                    READING WAS TAKEN AT 1550143 HOURS

CYCLE POINT  2                                       100 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          3.275 LB/SEC    AVG BURNER INLET TEMP   522. DEG F
AVG BURNER INLET PRES  89.6    PSIA      AVG BURNER OUTLET TEMP 1769. DEG F
AVG BURNER DELTA P      9.50    "HG      PRESSURE LOSS             5.21 %
OVERALL F/A RATIO      .01851* (F/M)     FUEL FLOW RATE          218.23 LB/HR
AIR LOAD FACTOR        1.1456            PATTERN FACTOR          .31584
BOT HOT SPOT:  # 21 = 2162.  DEG F       MAX BOT / AVG BOT       1.2224
FUEL INLET TEMPERATURE 159.  DEG F       FUEL INLET PRESSURE     487.9   PSIA
HEAT LOADING PARAMETER  .41455E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1580.  6 1548. 15 1932. 19 1857. 24 1981. 27 1946. 36 1342.
ANNULUS 2   4 1654.  7 1769. 16 2059. 21 2162. 25 2076. 34 1393. 37 1418.
ANNULUS 3   5 1628. 14 2036. 17 1818. 22 2050. 26 2081. 35 1314. 39 1507.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           89.55    PSIA    TOTAL PRESSURE          89.88   PSIA
STATIC PRESSURE          89.16    PSIA    STATIC PRESSURE         89.12   PSIA
VELOCITY DELTA P           .79     "HG    VELOCITY DELTA P          .94    "HG
AIR TEMPERATURE           522.  DEG F     AIR TEMPERATURE          522.  DEG F
AIR VELOCITY            121.33 FT/SEC     AIR VELOCITY           132.21 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.660    "HG

AIR FLOW DATA: P-REF= 101.7 PSIA   DELTA P= 5.28 "HG    T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       814.      HZ     VOLUMETRIC FLOW RATE  35.38 GAL/HR
FUEL PRESSURE AT F/M  551.2     PSIA      FUEL TEMP AT F/M          183.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    84.96 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              87.83 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 9.47  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    3.004 %     O2  16.800 %      CO    150.7 PPM      CHX       .0 PPM
 NO     40.8 PPM   NO2      9.7 PPM  NOX    50.5 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
  EMISSIONS INDEX, LB/1000 LB FUEL: CO=   0.44                  CHX=    .00
                   CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   4.41

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .014300
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7346 %
   CHECK ON F/A RATIO- F/A = .014306 W/O O2, CALCULATED O2 = 16.803 %

SMOKE INDEX: 11.0
SALTZMAN NOX = 72.9                PPM        E.I. = 6.37
---------------------------------------------------------------------------
REMARKS: *Low F/A for Cy. Pt. 2 - Limited by exit hot spots.
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Figure 264. Final Prechamber Liner Modification "A" on Pressure Atomizer Injection at Nonregenerative 100% Power.

TABLE LXXV. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL T63-A-5A COMBUSTOR LINER AND PRECHAMBER FINAL DESIGN COMBUSTION LINER MODIFICATION "A" OPERATING ON (2) WALL FUEL FILM INJECTION AND (3) CONVENTIONAL PRESSURE ATOMIZER INJECTION

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	392.7	651.5	495.5	382.9	214.1	74.7
H/C, (ppm)	100.0	37.0	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.1	45.8	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Prechamber Final Liner Mod. "A" Wall Fuel Film						
A. Emissions						
CO, (ppm)	162.7	158.7	156.7	168.8	166.8	NO DATA TAKEN
H/C, (ppm)	2.9	2.6	2.7	.8	2.3	
NO_x, (On-Line, NDIR & NDUV) (ppm)	19.1	25.0	29.3	39.1	49.9	
NO_x, (Saltzman) (ppm)	17.8	25.2	31.5	42.4	-	
Smoke Number	2.25	4.90	6.20	14.3	25.0	
B. Pressure Loss (%)	5.98	5.71	5.78	5.61	5.39	
C. Temp. Profile (T_{max}/T_{avg})	1.221	1.240	1.220	1.236	1.312	
III. Prechamber Final Liner Mod. "A" Pressure Atomizer						
A. Emissions						
CO, (ppm)	83.8	116.2	135.2	166.8	181.3	158.7*
H/C, (ppm)	.7	.2	.7	.1	.1	.1*
NO_x, (On-Line, NDIR & NDUV) (ppm)	19.0	23.1	32.7	38.7	48.1	50.5*
NO_x, (Saltzman) (ppm)	12.0	24.0	35.7	46.6	62.5	72.9*
Smoke Number	.00	.00	.00	2.95	11.2	11.0*
B. Pressure Loss (%)	5.86	5.64	5.76	5.83	5.66	5.21*
C. Temp. Profile (T_{max}/T_{avg})	1.133	1.141	1.154	1.150	1.170	1.222*

*Not true Cycle Point 2. F/A was low due to high temperature BOT hot spots (rapid rise in T_{max}/T_{avg}).

Due to a poor exhaust temperature profile, neither fuel mode of this Prechamber liner could be operated at 100% power conditions. As shown in Figure 265, hydrocarbon emissions remained below 3 ppm at all conditions. Carbon monoxide emissions, Figure 266, remained about the same as in the initial design under pressure atomizer operation, but the wall film vaporizer injection mode gave a significant reduction in total CO produced. Both fuel modes in Modification "A" were showing very similar emission levels and characteristics.

Nitrogen oxide emissions were lower in Modification "A" than in the initial design. As can be seen in Figure 267, there was essentially no difference in NO_x between the modes of fuel injection, and both sets of Prechamber data were well below Conventional T63 NO_x concentrations. The improvement in the wall fuel film injection mode can easily be seen in the CO vs NO_x emission tradeoff curves in Figure 268. As seen in Figure 269, smoke/particulates at the higher power operating conditions appeared to be lessened somewhat, although the liner changes in Modification "A" did not change the smoke generating characteristics of the combustor. From Figure 270, the degradation in temperature profile is apparent for both fuel injection modes. With the profile worsening dramatically at the higher power levels, it was not possible to obtain any data at 100% power conditions. The combustor skin temperatures for both fuel modes are given in Figures 271 and 272.

Total emissions for the Prechamber Modification "A" combustor were reduced below those of the initial design. Compared to the Conventional T63 combustor, the pressure atomizer gave a 55% total reduction with no constituent increase, and the wall fuel film mode gave a 52% total emission reduction; however, smoke remained above the conventional combustor level. Extrapolations of emission concentrations at 100% power were made to permit the computation of total duty-cycle emissions. Maximum power emissions accounted for only 5% of the cycle operating time; thus these extrapolations, if conservatively made, should not produce misleading total duty-cycle results.

Modification "B"

The "Prechamber Combustor Liner" was completely redesigned in Modification "B". A new leaner vaporizer tube replaced the initial vaporizer section. The airflow splits among the swirler, reaction-zone holes, and dilution-zone holes were readjusted, and the 1.50-inch cylindrical section which had been added downstream of the dilution holes was removed. This was not the "best" Prechamber version based upon nonregenerative emissions and combustor performance, but it was the Prechamber configuration tested at regenerative conditions, ambient startup conditions, and parametric conditions. The hoped-for improvements in performance resulting from the design changes

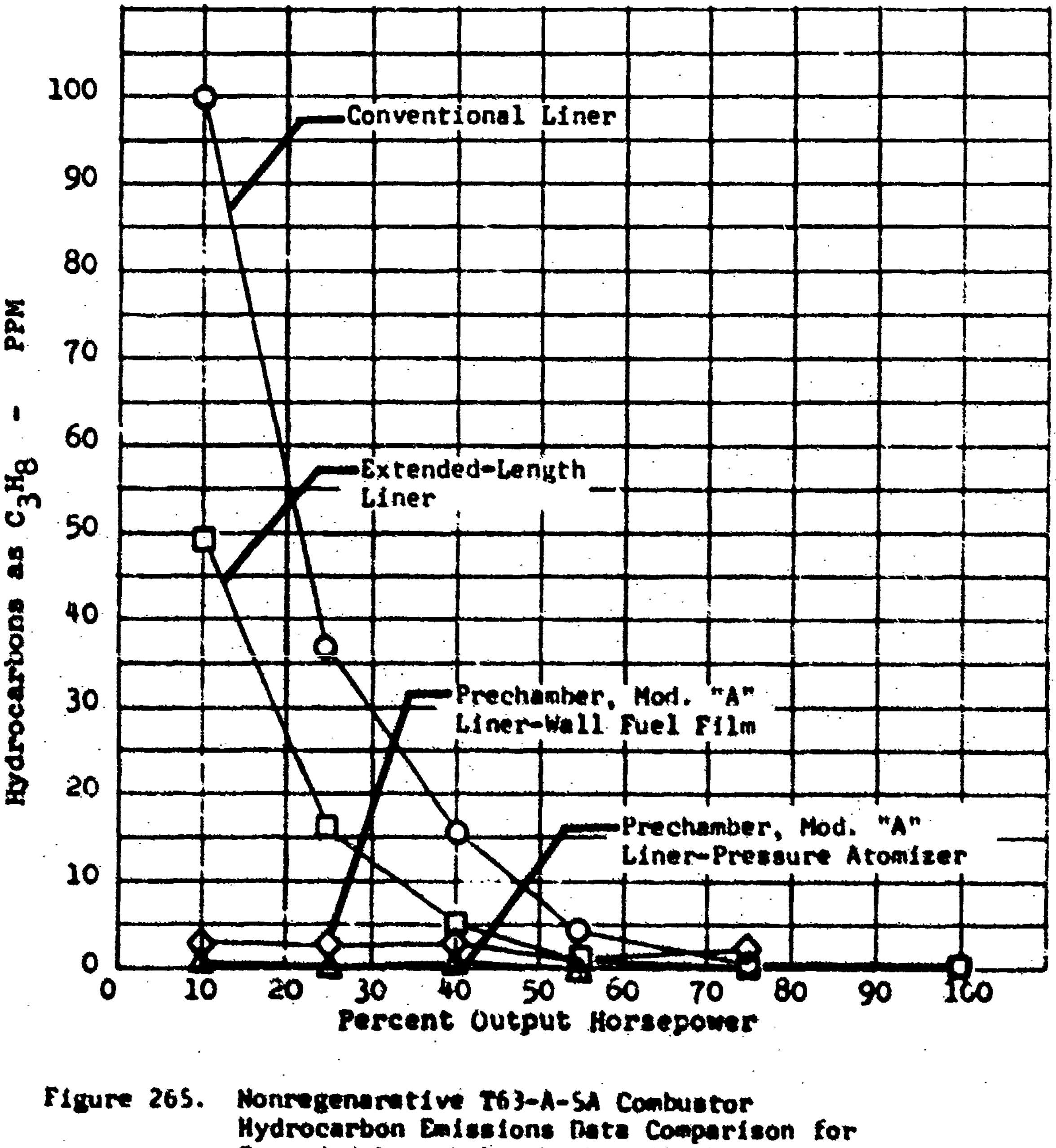

Figure 265. Nonregenerative T63-A-5A Combustor Hydrocarbon Emissions Data Comparison for Extended-Length, Prechamber Final Design, Modification "A" Combustor and T63 Baseline Combustors.

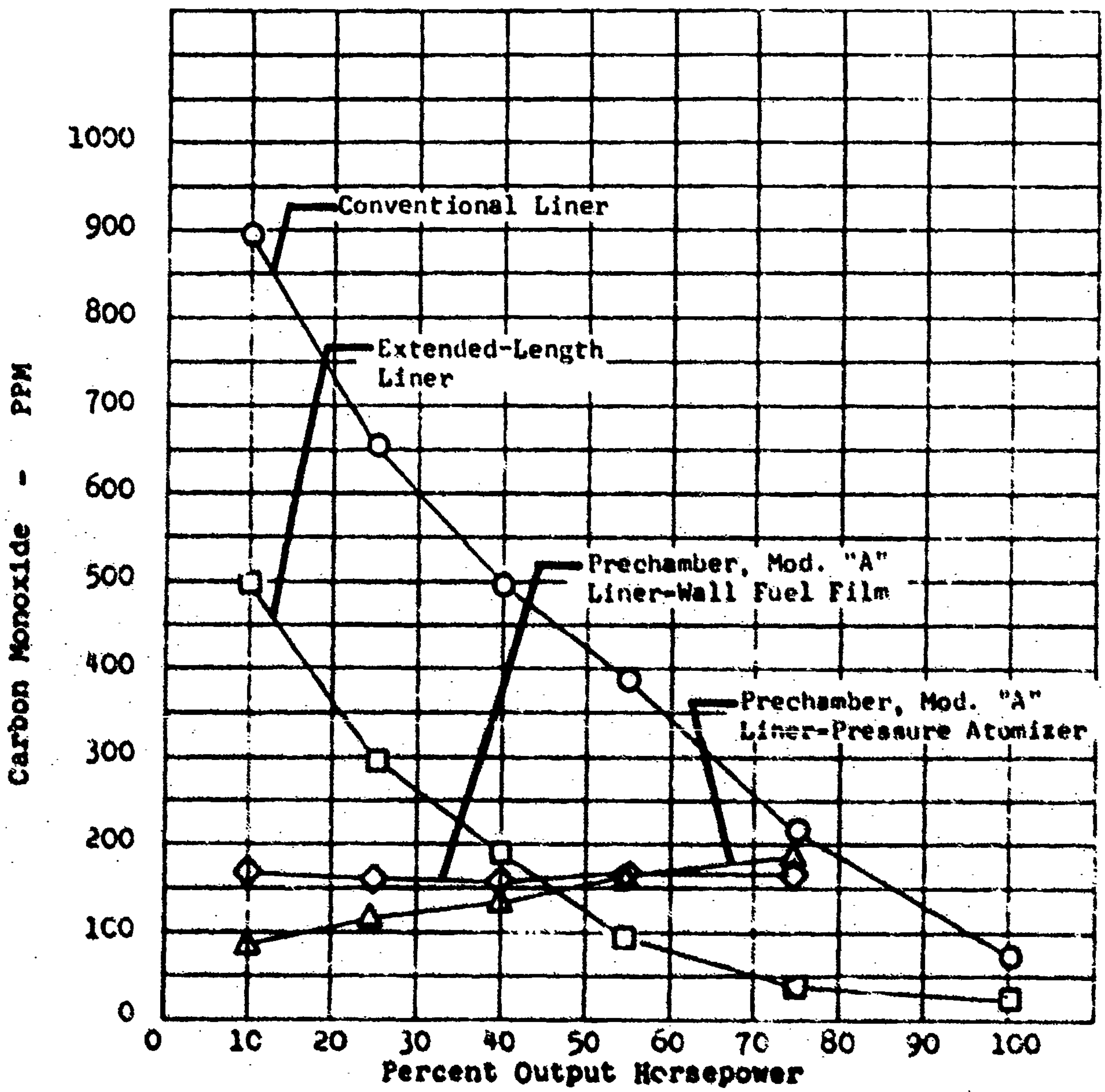

Figure 266. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emissions Data Comparison for Extended-Length, Prechamber Final Design, Modification "A" Combustor and T63 Baseline Combustors.

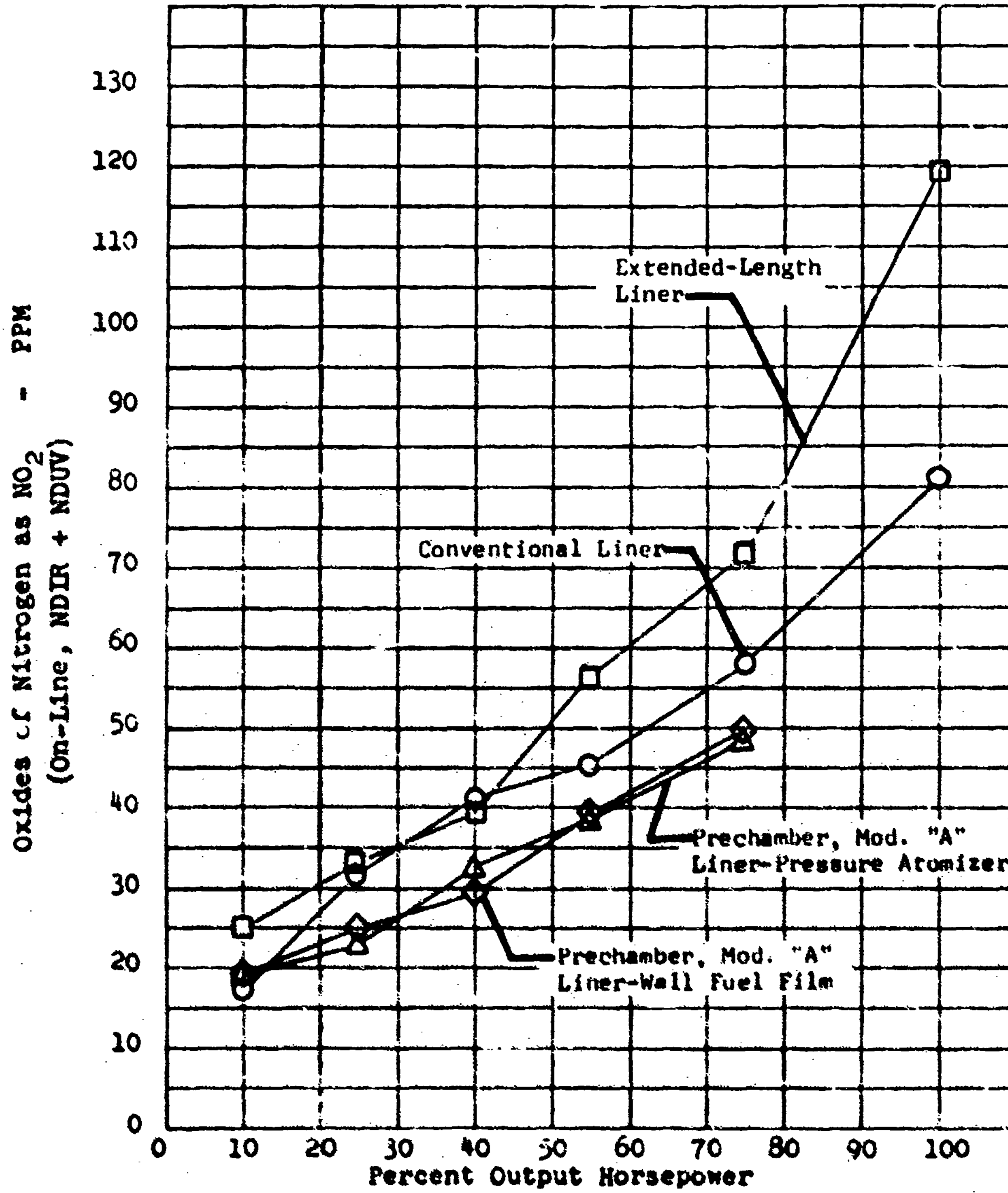

Figure 267. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emissions Data Comparison for Extended-Length Prechamber Final Design, Modification "A" Combustor and T63 Baseline Combustors.

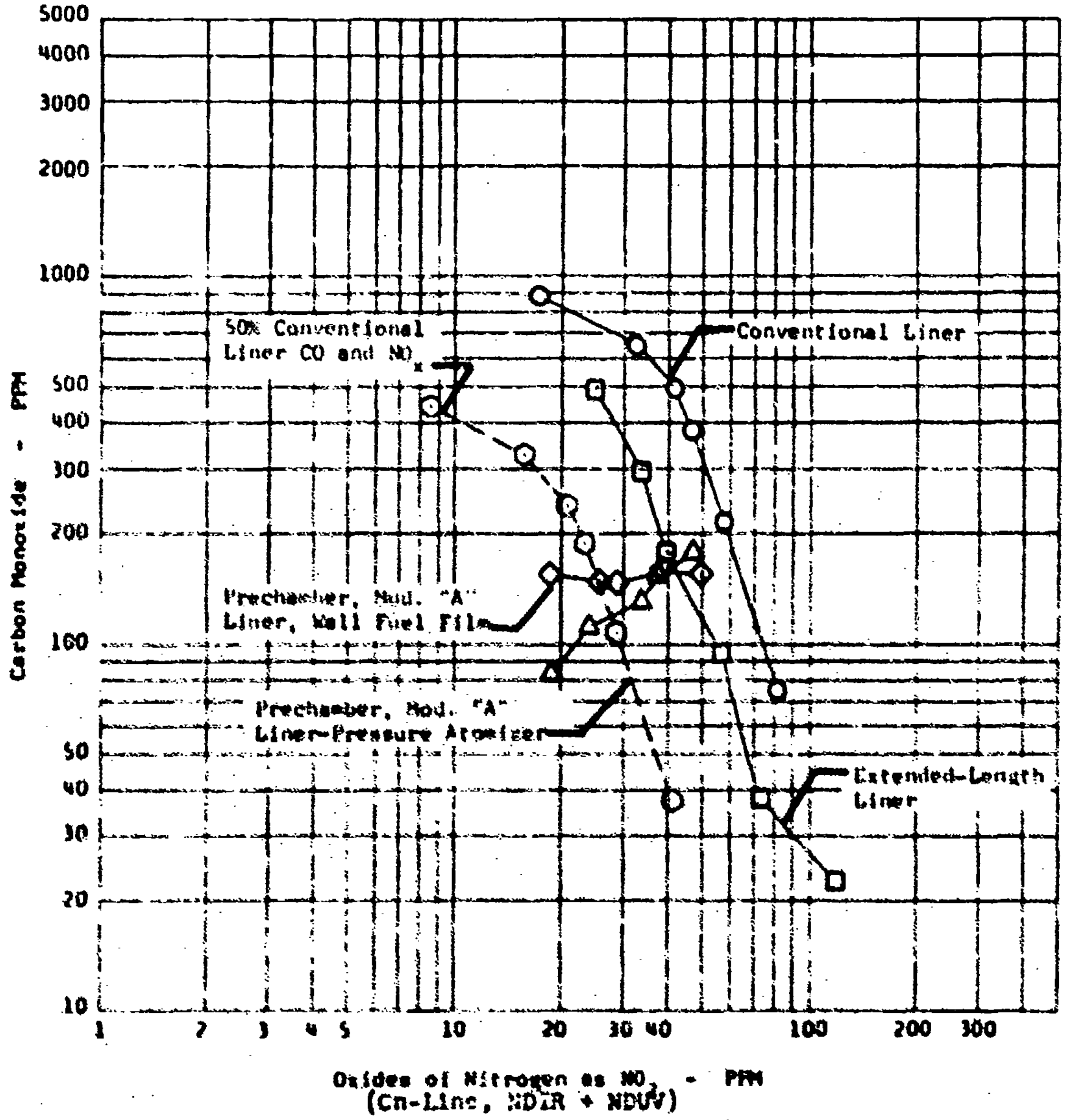

Figure 268. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Data Comparison for Extended-Length, Prechamber Final Design, Modification "A" Combustor and T63 Baseline Combustors.

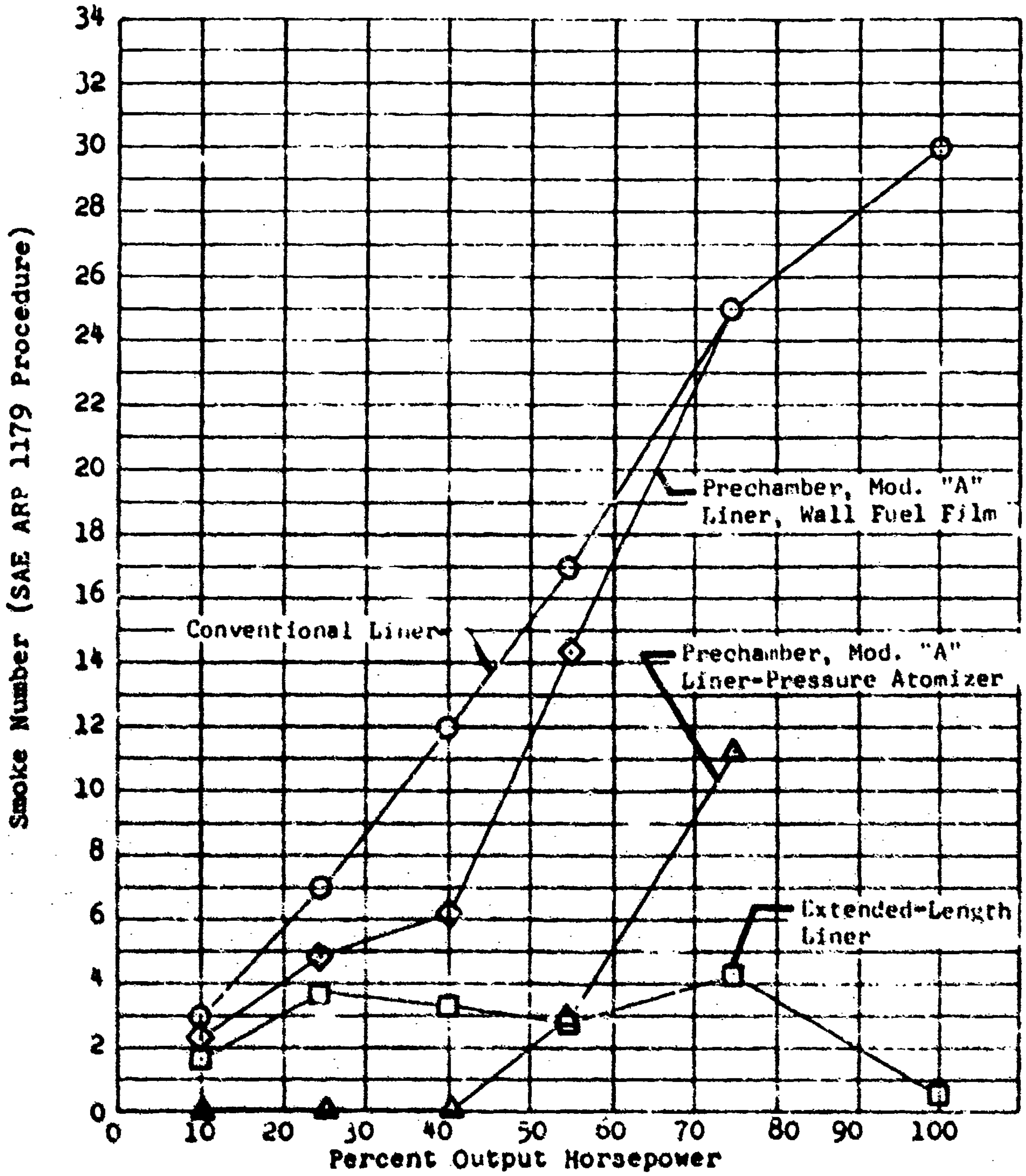

Figure 269. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Prechamber Final Design, Modification "A" Combustor and Baseline T63 Baseline Combustors.

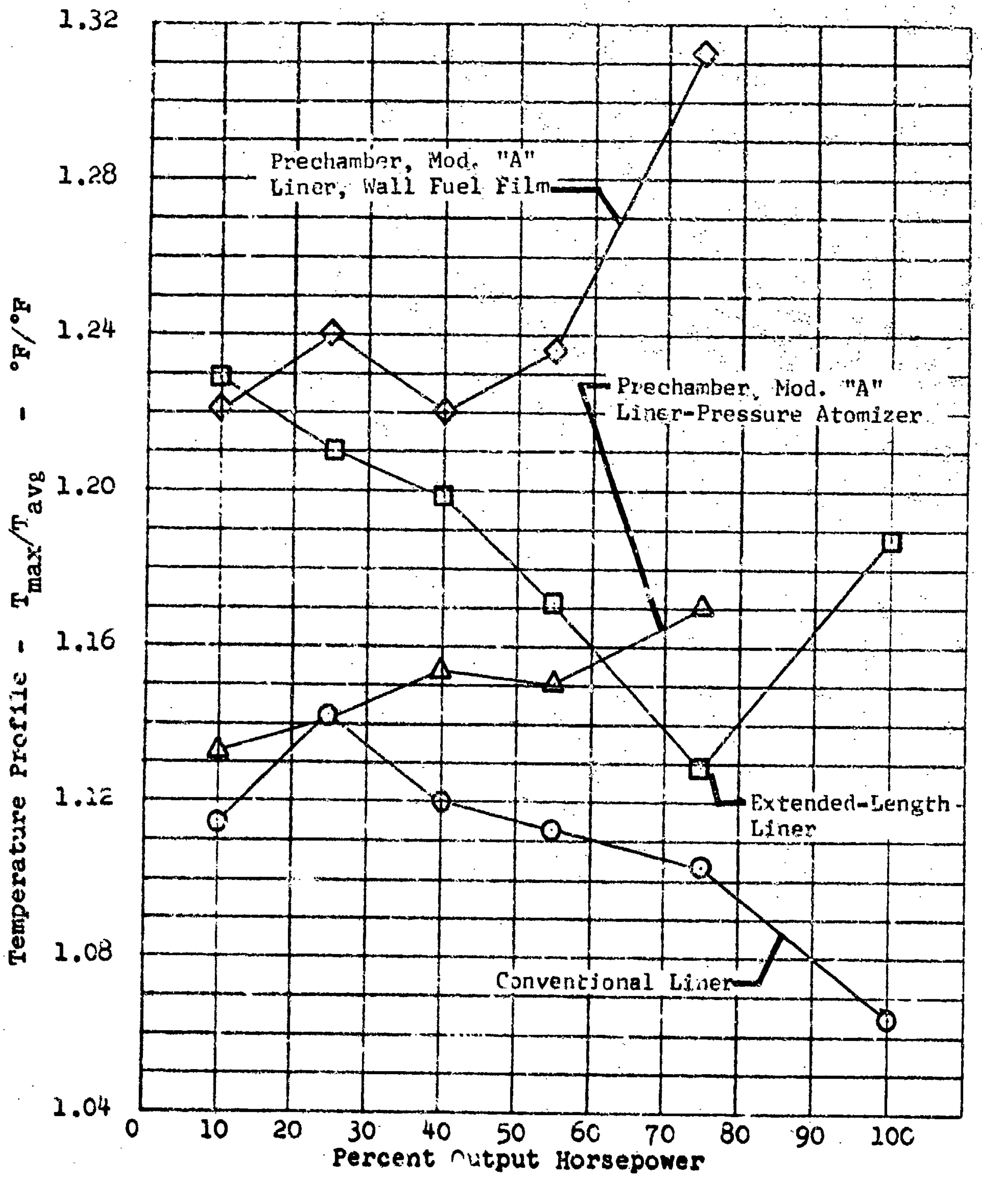

Figure 270. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Prechamber Final Design Modification "A" Combustor and T63 Baseline Combustor.

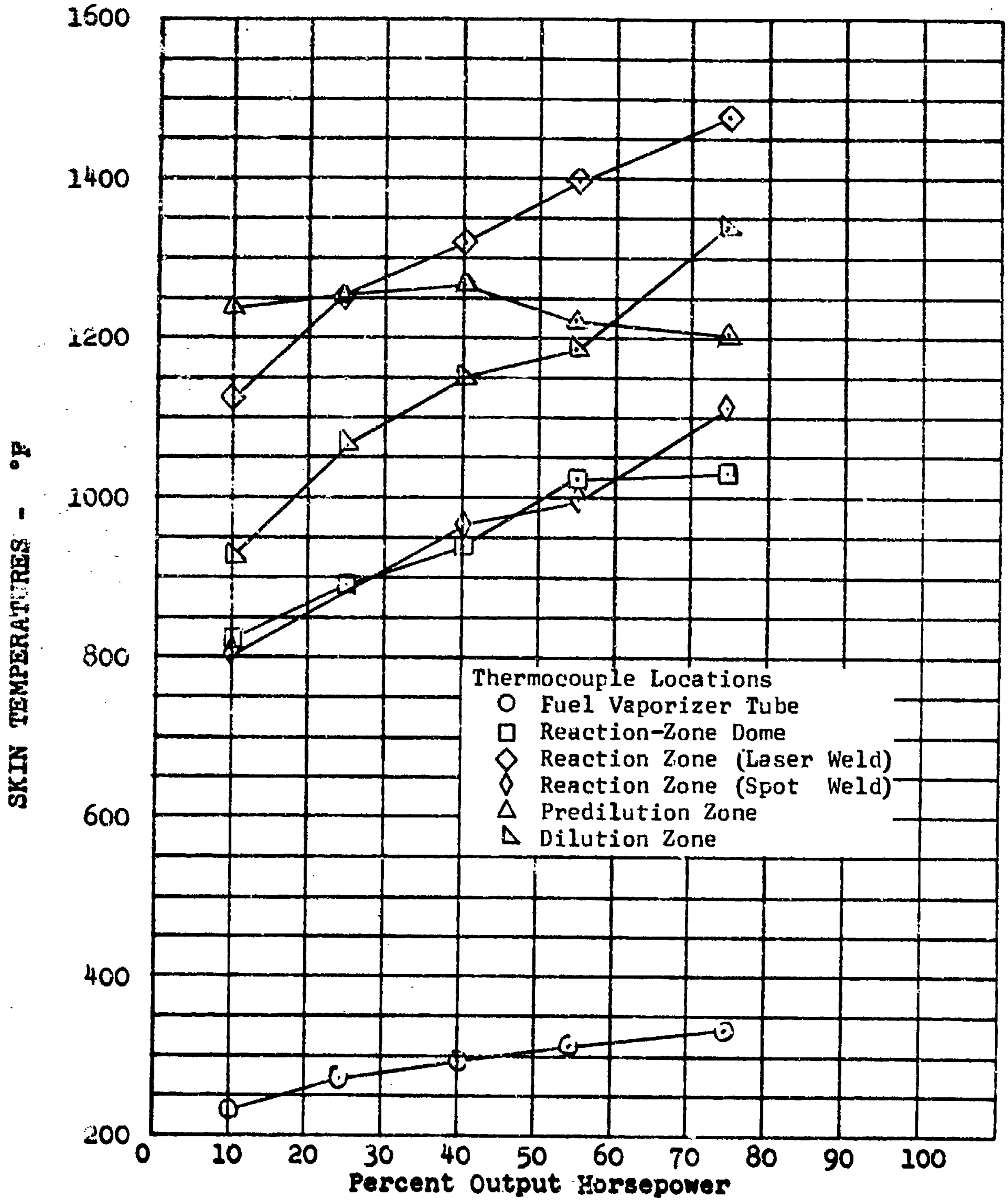

Figure 271. Nonregenerative T63-A-5A Combustor Skin Temperatures Prechamber Final Design Combustor, Modification "A" Operating on Wall Fuel Film Injection.

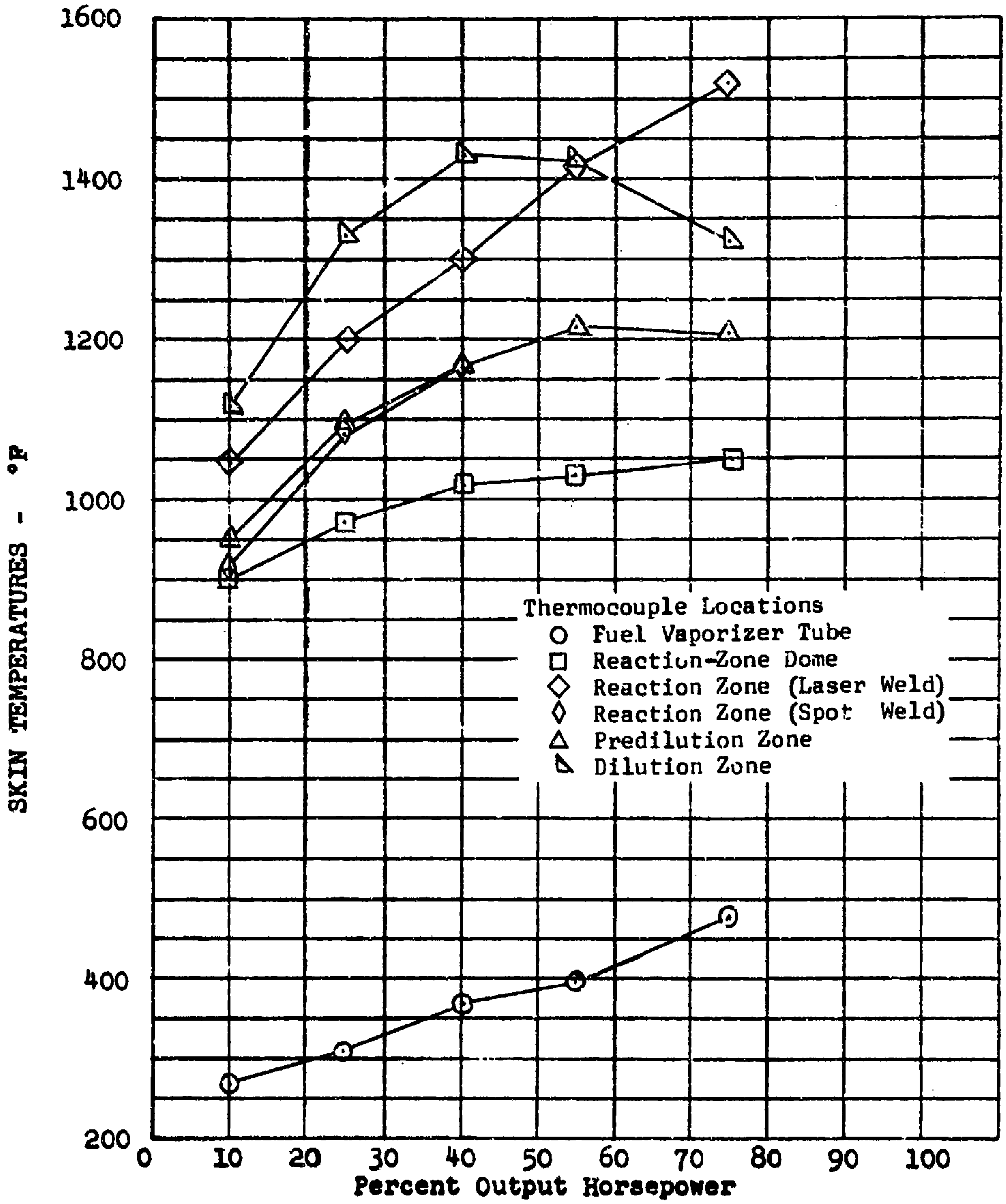

Figure 272. Nonregenerative T63-A-5A Combustor Skin Temperatures Prechamber Final Design Combustor, Modification "A" Operating on Pressure Atomizer Injection.

from Modification "A" to Modification "B" did not materialize, but the final series of required tests was conducted since there was insufficient time for additional major design changes.

The nonregenerative test results are given in Figures 273 through 277 for the Prechamber Modification "B" operating on wall fuel film injection and in Figures 278 through 284 for pressure atomizer injection. Emission, pressure-loss, and exhaust-temperature profile data are summarized in Table LXXVI. Prechamber pressure losses remained 1% - 1.5% higher than the conventional T63 combustor.

Of significance was the major increase in the hydrocarbon concentration when the combustor was operated on the wall fuel film. Concentrations using the pressure atomizer increased but were still very low, as is evidenced in Figure 285. Carbon monoxide increased enough at low-power conditions to eliminate any chance of achieving the 50% reduction in total emissions. As can be seen in Figure 286, CO at idle (10% power) was reduced by only one-third when the Prechamber and Conventional concentrations are compared. Modification "B" produced an increase in NO_x compared to the previous design when operating on the pressure atomizer and showed no effective change in NO_x when operated on the wall film. From Figure 287, it can be seen that the total NO_x levels produced by the preliminary "Prechamber Combustor Liner" were not attained. The CO vs NO_x emission tradeoff in Figure 288 shows that the Modification "B" emissions are lower than those produced by the Conventional combustor, but additional reductions in wall fuel film-produced CO concentrations are still required.

The success of Modification "B" in reducing smoke/particulates when operating on the wall fuel film is apparent in Figure 289. For the pressure atomizer fuel mode, however, the smoke increased to the highest levels measured in a "Final Prechamber Combustor". The exhaust temperature profiles in Figure 290 were also the highest of any of the "Final Prechamber" configurations operating on either fuel injection mode.

Again, based on extrapolated emissions at 100% power so that total duty-cycle emissions could be computed, the Modification "B" combustor operating on pressure atomizer injection reduced total emissions by 57% but produced four times as much smoke/particulates as the conventional combustor over the duty cycle. When operating on wall fuel film injection, Modification "B" could reduce the total emissions by only 39%, the least of any Prechamber tested. The great reductions in smoke gained by Prechamber Modification "B" were more than offset by the large increases in hydrocarbons, which exceeded the baseline levels by 35%.

Lean blowout data from idle were obtained for the Prechamber Modification "B" liner. Under wall fuel film operation, lean blowout

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 77, READING #    883
T63 FINAL PRECHAMBER, MOD "B" RUN AT STD T63 INLET ON FILM NOZZLE.
TEST DATE:  8 -6-72                      READING WAS TAKEN AT 174812S HOURS

CYCLE POINT  1                                         10 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.912 LB/SEC    AVG BURNER INLET TEMP    301. DEG F
AVG BURNER INLET PRES  44.9    PSIA      AVG BURNER OUTLET TEMP 1048. DEG F
AVG BURNER DELTA P      5.47    "HG      PRESSURE LOSS             5.08 %
OVERALL F/A RATIO      .01096  (F/M)     FUEL FLOW RATE           75.43 LB/HR
AIR LOAD FACTOR        1.1731            PATTERN FACTOR          .61874
BOT HOT SPOT:  # 16 = 1510.  DEG F       MAX BOT / AVG BOT       1.4411
FUEL INLET TEMPERATURE  85.  DEG F       FUEL INLET PRESSURE       41.3  PSIA
HEAT LOADING PARAMETER  .29947E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  786.  6  752. 15 1354. 19 1265. 24 1065. 27  969. 36 1280.
ANNULUS 2   4  869.  7  777. 16 1510. 21  905. 25  940. 34 1029. 37 1333.
ANNULUS 3   5  719. 14 1321. 17 1474. 22  928. 26  829. 35  997. 39  899.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           44.90   PSIA    TOTAL PRESSURE          44.99   PSIA
STATIC PRESSURE          44.65   PSIA    STATIC PRESSURE         44.68   PSIA
VELOCITY DELTA P           .50    "HG    VELOCITY DELTA P          .64    "HG
AIR TEMPERATURE           301.  DEG F    AIR TEMPERATURE          301.  DEG F
AIR VELOCITY           119.39 FT/SEC     AIR VELOCITY           135.77 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.193    "HG

AIR FLOW DATA: P-REF= 105.4 PSIA   DELTA P= 1.64 "HG   T-REF=  81. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       278.      HZ    VOLUMETRIC FLOW RATE  12.12 GAL/HR
FUEL PRESSURE AT F/M  233.2    PSIA      FUEL TEMP AT F/M          85.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     42.26 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              44.11 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 5.37  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2    1.817 %     O2  18.900 %     CO    619.2 PPM     CHX   140.0 PPM
 NO      4.2 PPM  NO2      8.1 PPM  NOX     12.2 PPM [NO(NDIR) + NO2(NDUV)]
 NO      5.5 PPM  NO2      6.5 PPM  NOX     12.0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  55.23                  CHX=  19.66
              CHEMILUMINESCENCE NOX=   1.76,    NDIR + NDUV NOX=    1.79

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .008998
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  96.0046 %
   CHECK ON F/A RATIO- F/A = .009201 W/O O2, CALCULATED O2 = 18.422 %

SMOKE INDEX: 0.10
SALTZMAN NOX = 10.4                   PPM
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Figure 273. Final Prechamber Liner Modification "B" on Wall Fuel Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 77, READING #     884
T63 FINAL PRECHAMBER, MOD "B" RUN AT STD T63 INLET ON FILM NOZZLE.
TEST DATE: 8 -8-72                       READING WAS TAKEN AT 1816:49 HOURS

CYCLE POINT  6                                          25 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.180 LB/SEC     AVG BURNER INLET TEMP    354. DEG F
AVG BURNER INLET PRES  54.7    PSIA     AVG BURNER OUTLET TEMP 1204. DEG F
AVG BURNER DELTA P      5.74     "HG     PRESSURE LOSS              5.15 %
OVERALL F/A RATIO     .01200  (F/M)     FUEL FLOW RATE            94.19 LB/HR
AIR LOAD FACTOR        1.1366             PATTERN FACTOR           .50553
BOT HOT SPOT:  # 17 = 1633.  DEG F      MAX BOT / AVG BOT        1.3570
FUEL INLET TEMPERATURE  88.  DEG F      FUEL INLET PRESSURE        50.9   PSIA
HEAT LOADING PARAMETER  .30726E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  994.  6  970. 15 1483. 19 1406. 24 1237. 27 1041. 36 1471.
ANNULUS 2   4 1033.  7  998. 16 1626. 21 1047. 25 1039. 34 1234. 37 1543.
ANNULUS 3   5  906. 14 1451. 17 1633. 22 1031. 26  924. 35 1210. 39  999.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           54.64    PSIA    TOTAL PRESSURE           54.76   PSIA
STATIC PRESSURE          54.50    PSIA    STATIC PRESSURE          54.48   PSIA
VELOCITY DELTA P           .28     "HG    VELOCITY DELTA P           .56    "HG
AIR TEMPERATURE           354.  DEG F     AIR TEMPERATURE           354.  DEG F
AIR VELOCITY             84.67 FT/SEC     AIR VELOCITY            119.26 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]     -.234    "HG

AIR FLOW DATA: P-REF= 104.6 PSIA   DELTA P= 2.13 "HG   T-REF=  83. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       347.      HZ     VOLUMETRIC FLOW RATE  15.16 GAL/HR
FUEL PRESSURE AT F/M   223.7    PSIA    FUEL TEMP AT F/M           88.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     51.88 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              53.78 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 5.62  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   2.156 %    O2  16.400 %    CO    289.6 PPM     CHX    40.0 PPM
 NO     8.4 PPM  NO2     8.9 PPM  NOX    17.3 PPM [NO(NDIR) + NO2(NDUV)]
 NO    10.8 PPM  NO2     7.5 PPM  NOX    18.3 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  23.51                  CHX=   5.13
                  CHEMILUMINESCENCE NOX=   2.45,   NDIR + NDUV NOX=   2.32

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .010301
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.7717 %
   CHECK ON F/A RATIO- F/A = .010808 W/O O2, CALCULATED O2 = 17.075 %

SMOKE INDEX: 1.82
SALTZMAN NOX = 19.6              PPM
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Figure 274. Final Prechamber Liner Modification "B" on Wall Fuel Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 77, READING #     885
T63 FINAL PRECHAMBER, MOD "B" RUN AT STD T63 INLET ON FILM NOZZLE.
TEST DATE: 8 -8-72                         READING WAS TAKEN AT 1840:18 HOURS

CYCLE POINT  5                                              40 % POWER SETTING

                      ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.523 LB/SEC     AVG BURNER INLET TEMP   399. DEG F
AVG BURNER INLET PRES   64.1   PSIA      AVG BURNER OUTLET TEMP 1307. DEG F
AVG BURNER DELTA P       7.73    "HG      PRESSURE LOSS            5.92 %
OVERALL F/A RATIO      .01310  (F/M)     FUEL FLOW RATE         118.99 LB/HR
AIR LOAD FACTOR        1.1531            PATTERN FACTOR          .39836
HOT HOT SPOT:  # 16 = 1669. DEG F        MAX BOT / AVG BOT      1.2768
FUEL INLET TEMPERATURE  90.   DEG F      FUEL INLET PRESSURE      60.4  PSIA
HEAT LOADING PARAMETER  .33110E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
          ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1181,  6 1133. 15 1528. 19 1409. 24 1433. 27 1319. 36 1403.
ANNULUS 2  4 1166.  7 1148. 16 1669. 21 1118. 25 1323. 34 1322. 37 1438.
ANNULUS 3  5 1041. 14 1444. 17 1611. 22 1164. 26 1245. 35 1309. 39 1061.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE         64.09   PSIA     TOTAL PRESSURE          64.17  PSIA
STATIC PRESSURE        63.66   PSIA     STATIC PRESSURE         63.94  PSIA
VELOCITY DELTA P         .87   "HG      VELOCITY DELTA P          .47   "HG
AIR TEMPERATURE         399.  DEG F     AIR TEMPERATURE          399.  DEG F
AIR VELOCITY          140.37 FT/SEC     AIR VELOCITY           102.97 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]      -.170    "HG

AIR FLOW DATA: P-REF= 103.7 PSIA   DELTA P= 2.93 "HG    T-REF=  82. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       438.      HZ    VOLUMETRIC FLOW RATE  19.17 GAL/HR
FUEL PRESSURE AT F/M   215.5     PSIA    FUEL TEMP AT F/M        90.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    60.33 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             62.95 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.66  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.401 %      O2  17.900 %     CO    107.8 PPM      CHX      9.5 PPM
 NO     14.8 PPM  NO2     12.3 PPM  NOX     27.1 PPM (NO(NDIR) + NO2(NDUV))
 NO     18.6 PPM  NO2      8.9 PPM  NOX     27.5 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    9.53               CHX=    1.10
                   CHEMILUMINESCENCE NOX=    3.30,    NDIR + NDUV NOX=   3.33

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011412
 CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6061 %
   CHECK ON F/A RATIO= F/A = .011549 W/O O2, CALCULATED O2 = 17.646 %

SMOKE INDEX: 0.96
SALTZMAN NOX = 30.3               PPM
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Figure 275. Final Prechamber Liner Modification "B" on Wall Fuel Injection at Nonregenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 77, READING #    886
T63 FINAL PRECHAMBER, MOD "B" RUN AT STD T63 INLET ON FILM NOZZLE.
TEST DATE: 8 -8-72                        READING WAS TAKEN AT 1922:22 HOURS

CYCLE POINT  4                                          55 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.710 LB/SEC    AVG BURNER INLET TEMP   430. DEG F
AVG BURNER INLET PRES  70.8    PSIA      AVG BURNER OUTLET TEMP 1444. DEG F
AVG BURNER DELTA P      8.34    "HG      PRESSURE LOSS            5.79 %
OVERALL F/A RATIO     .01460  (F/P)      FUEL FLOW RATE         142.44 LB/HR
AIR LOAD FACTOR        1.1414            PATTERN FACTOR         .41274
BOT HOT SPOT: # 17 = 1863.  DEG F        MAX BOT / AVG BOT      1.2899
FUEL INLET TEMPERATURE  91.  DEG F       FUEL INLET PRESSURE     67.9  PSIA
HEAT LOADING PARAMETER  .35893E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1344.  6 1245. 15 1663. 19 1556. 24 1528. 27      . 36 1567.
ANNULUS 2   4 1307.  7 1275. 16 1843. 21 1286. 25 1436. 34 1504. 37 1612.
ANNULUS 3   5 1153. 14 1648. 17 1863. 22 1282. 26 1356. 35 1475. 39 1170.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          70.77   PSIA     TOTAL PRESSURE         70.85   PSIA
STATIC PRESSURE         70.44   PSIA     STATIC PRESSURE        70.55   PSIA
VELOCITY DELTA P          .67    "HG     VELOCITY DELTA P         .60    "HG
AIR TEMPERATURE         430.  DEG F      AIR TEMPERATURE        430.  DEG F
AIR VELOCITY          119.39 FT/SEC      AIR VELOCITY         113.20 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))     -.152     "HG

AIR FLOW DATA: P-REF= 103.4 PSIA   DELTA P= 3.30 "HG   T-REF=  81. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       525.      HZ    VOLUMETRIC FLOW RATE  22.90 GAL/HR
FUEL PRESSURE AT F/M  207.3    PSIA      FUEL TEMP AT F/M          92.  DEG F

             ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    66.71 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             69.36 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.26  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2    2.625 %      O2   17.400 %     CO    166.8 PPM      CHX      7.8 PPM
 NO      18.3 PPM   NO2     17.2 PPM  NOX      35.5 PPM (NO(NDIR) + NO2(NDUV))
 NO      24.9 PPM   NO2     16.3 PPM  NOX      41.1 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.21                   CHX=     .70
               CHEMILUMINESCENCE NOX=   4.54,    NDIR + NDUV NOX=     3.91

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .012677
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.9290 %
   CHECK ON F/A RATIO- F/A = .012618 W/O O2, CALCULATED O2 = 17.330 %

SMOKE INDEX: 0.11
SALTZMAN NOX = 39.9              PPM
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Figure 276. Final Prechamber Liner Modification "B" on Wall Fuel Injection at Nonregenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 77, READING #    807
T63 FINAL PRECHAMBER, MOD "B" RUN AT STD T63 INLET ON FILM NOZZLE.
TEST DATE: 8 -8-72                      READING WAS TAKEN AT 194924 HOURS

CYCLE POINT  3                                         75 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          3.035 LB/SEC     AVG BURNER INLET TEMP   470. DEG F
AVG BURNER INLET PRES   80.9    PSIA      AVG BURNER OUTLET TEMP 1611. DEG F
AVG BURNER DELTA P       9.56    "HG      PRESSURE LOSS             5.81 %
OVERALL F/A RATIO       .01660  (F/M)     FUEL FLOW RATE          181.38 LB/HR
AIR LOAD FACTOR         1.1443            PATTERN FACTOR          .30640
BOT HOT SPOT: # 17 = 2052.  DEG F         MAX BOT / AVG BOT       1.2737
FUEL INLET TEMPERATURE  92.  DEG F        FUEL INLET PRESSURE      79.5  PSIA
HEAT LOADING PARAMETER  .49017E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1478.  6 1371. 15 1878. 19 1808. 24 1713. 27 1490. 36 1803.
ANNULUS 2   4 1438.  7 1410. 16 2032. 21 1287. 25 1604. 34 1718. 37 1844.
ANNULUS 3   5 1271. 14 1891. 17 2052. 22 1309. 26 1485. 35 1654. 39 1294.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE         80.83   PSIA     TOTAL PRESSURE          80.99   PSIA
STATIC PRESSURE        80.54   PSIA     STATIC PRESSURE         80.33   PSIA
VELOCITY DELTA P         .59    "HG     VELOCITY DELTA P         1.15    "HG
AIR TEMPERATURE         470.  DEG F     AIR TEMPERATURE          470.  DEG F
AIR VELOCITY          106.70 FT/SEC     AIR VELOCITY           140.60 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.138    "HG

AIR FLOW DATA: P-REF= 103.0 PSIA   DELTA P= 4.26 "HG   T-REF=  70. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       671.      HZ     VOLUMETRIC FLOW RATE  26.28 GAL/HR
FUEL PRESSURE AT F/M   195.9    PSIA      FUEL TEMP AT F/M          93.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   76.17 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             79.78 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                9.40  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    2.953 %     O2  16.000 %     CO   173.0 PPM     CHX     2.1 PPM
 NO     32.3 PPM  NO2    19.3 PPM  NOX    51.6 PPM (NO(NDIR) + NO2(NDUV))
 NO     37.3 PPM  NO2    13.0 PPM  NOX    50.9 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.30                CHX=    .26
                  CHEMILUMINESCENCE NOX=   6.14,   NDIR + NDUV NOX=   6.02

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:      .014206
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8816 %
   CHECK ON F/A RATIO- F/A = .014188 W/O O2, CALCULATED O2 = 16.072 %

SMOKE INDEX: 3.26
SALTZMAN NOX = 55.9          PPM
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Figure 277. Final Prechamber Liner Modification "B" on Wall Fuel Injection at Nonregenerative 75% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 67, TEST SERIES 78, READING #    889
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND, ON PRESSURE NOZZLE
TEST DATE: 8 -9-72                       READING WAS TAKEN AT 111126 HOURS

CYCLE POINT  1                                        10 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         1.855 LB/SEC    AVG BURNER INLET TEMP   381. DEG F
AVG BURNER INLET PRES  44.5    PSIA     AVG BURNER OUTLET TEMP 1062. DEG F
AVG BURNER DELTA P      5.17    "HG     PRESSURE LOSS            5.70 %
OVERALL F/A RATIO      .01094  (F/P)    FUEL FLOW RATE          73.03 LB/HR
AIR LOAD FACTOR        1.1489           PATTERN FACTOR         .34028
BOT HOT SPOT: # 16 = 1321.  DEG F       MAX BOT / AVG BOT      1.2438
FUEL INLET TEMPERATURE  83.  DEG F      FUEL INLET PRESSURE    103.3  PSIA
HEAT LOADING PARAMETER  .29259E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  973.  6  986. 15 1233. 19 1147. 24 1196. 27 1047. 36 1178.
ANNULUS 2   4  982.  7  932. 16 1321. 21  868. 25 1085. 34 1149. 37 1227.
ANNULUS 3   5  839. 14 1162. 17 1248. 22  880. 26  985. 35 1077. 38  864.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE            44.53    PSIA   TOTAL PRESSURE         44.55   PSIA
STATIC PRESSURE           44.34    PSIA   STATIC PRESSURE        44.22   PSIA
VELOCITY DELTA P            .39    "HG    VELOCITY DELTA P         .67   "HG
AIR TEMPERATURE            381.  DEG F    AIR TEMPERATURE         381.  DEG F
AIR VELOCITY            108.42 FT/SEC     AIR VELOCITY         138.14 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.030    "HG

AIR FLOW DATA: P-REF= 145.5 PSIA   DELTA P= 1.55 "HG   T-REF=  83. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        289.       HZ    VOLUMETRIC FLOW RATE  11.72 GAL/HR
FUEL PRESSURE AT F/M   293.4      PSIA    FUEL TEMP AT F/M          83.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    42.08 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              43.69 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 5.15  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE 01
CO2    2.034 %     O2  18.400 %      CO    180.7 PPM      CHX     13.0 PPM
 NO      4.9 PPM  NO2      6.8 PPM  NOX     11.7 PPM (NO(NDIR) + NO2(NDUV))
 NO      8.2 PPM  NO2      2.6 PPM  NOX     10.8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  14.01                     CHX=   1.03
                   CHEMILUMINESCENCE NOX=   1.58,    NDIR + NDUV NOX=   1.72

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .008717
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.4278 %
   CHECK ON F/A RATIO- F/A = .008828 W/O O2, CALCULATED O2 = 18.188 %

SMOKE INDEX: 7.13
SALTZMAN NOX = 16.3                   PPM
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Figure 278. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 78, READING #    898
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND. ON PRESSURE NOZZLE
TEST DATE:  6 -9-72                    READING WAS TAKEN AT 113S:24 HOURS

CYCLE POINT  6                                       25 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.246 LB/SEC    AVG BURNER INLET TEMP   385. DEG F
AVG BURNER INLET PRES  54.6    PSIA     AVG BURNER OUTLET TEMP 1208. DEG F
AVG BURNER DELTA P      6.37    "HG     PRESSURE LOSS             5.73 %
OVERALL F/A RATIO      .01211  (F/P)    FUEL FLOW RATE           97.98 LB/HR
AIR LOAD FACTOR        1.1738           PATTERN FACTOR          .32894
HOT HOT SPOT:  # 16 = 1479.  DEG F      MAX BOT / AVG BOT       1.2317
FUEL INLET TEMPERATURE  85.  DEG F      FUEL INLET PRESSURE     223.7  PSIA
HEAT LOADING PARAMETER  .31996E+07 BTU/HOUR/ATM/CUBIC FOOT

               **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1134.  6 1455. 15 1387. 19 1284. 24 1348. 27 1169. 36 1318.
ANNULUS 2  4 1162.  7 1463. 16 1478. 21  982. 25 1282. 34 1281. 37 1378.
ANNULUS 3  5  998. 14 1277. 17 1483. 22 1087. 26 1111. 35 1283. 38  983.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           54.59   PSIA   TOTAL PRESSURE            54.60   PSIA
STATIC PRESSURE          54.38   PSIA   STATIC PRESSURE           54.43   PSIA
VELOCITY DELTA P           .44    "HG   VELOCITY DELTA P            .34    "HG
AIR TEMPERATURE          355.  DEG F    AIR TEMPERATURE           358.  DEG F
AIR VELOCITY            105.12 FT/SEC   AIR VELOCITY              93.28 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.022    "HG

AIR FLOW DATA: P-REF= 145.8 PSIA   DELTA P= 2.38 "HG   T-REF=  88. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       368.      HZ   VOLUMETRIC FLOW RATE  15.73 GAL/HR
FUEL PRESSURE AT F/M   208.8   PSIA     FUEL TEMP AT F/M         86.  DEG F

             ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   51.67 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            53.71 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               6.38  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2   2.254 %      O2  14.400 %     CO      87.2 PPM     CHX     2.4 PPM
 NO     12.8 PPM  NO2      7.6 PPM  NOX     19.6 PPM (NO(NDIR) + NO2(NDUV))
 NO     19.3 PPM  NO2       .0 PPM  NOX     19.3 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    7.86                 CHX=     .31
                 CHEMILUMINESCENCE NOX=   2.57,    NDIR + NDUV NOX=    2.60

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .012929
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7913 %
   CHECK ON F/A RATIO- F/A = .010826 W/O O2, CALCULATED O2 = 17.854 %

SMOKE INDEX: 14.11
SALTZMAN NOX = 21.7                     PPM
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Figure 279. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 6/U 67, TEST SERIES 78, READING #    891
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND. ON PRESSURE NOZZLE
TEST DATE:  5 -9-72                      READING WAS TAKEN AT 121846 HOURS

CYCLE POINT  5                                          40 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.514 LB/SEC    AVG BURNER INLET TEMP   396. DEG F
AVG BURNER INLET PRES  63.2    PSIA     AVG BURNER OUTLET TEMP 1308. DEG F
AVG BURNER DELTA P      7.28    "HG     PRESSURE LOSS             5.66 %
OVERALL F/A RATIO     .01316  (F/M)     FUEL FLOW RATE          119.07 LB/HR
AIR LOAD FACTOR116304000.000            PATTERN FACTOR           .33001
BOT HOT SPOT: # 16 = 1609.  DEG F       MAX BOT / AVG BOT        1.2302
FUEL INLET TEMPERATURE  89.  DEG F      FUEL INLET PRESSURE     250.4  PSIA
HEAT LOADING PARAMETER  .33612E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1259.  6 115-. 15 1517. 19 1349. 24 1450. 27 1288. 36 1433.
ANNULUS 2   4 1293.  7 1163. 16 1609. 21 1051. 25 1337. 34 1344. 37 1543.
ANNULUS 3   5 1104. 14 1376. 17 1554. 22 1061. 26 1209. 35 1311. 39 1063.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE             63.14   PSIA    TOTAL PRESSURE         63.20   PSIA
STATIC PRESSURE            62.73   PSIA    STATIC PRESSURE        62.98   PSIA
VELOCITY DELTA P             .83    "HG    VELOCITY DELTA P         .68    "HG
AIR TEMPERATURE             396.  DEG F    AIR TEMPERATURE         396.  DEG F
AIR VELOCITY             137.73 FT/SEC     AIR VELOCITY          125.00 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.208    "HG

AIR FLOW DATA: P-REF= 144.0 PSIA   DELTA P=  .23 "HG    T-REF=  89. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       430.       HZ     VOLUMETRIC FLOW RATE  18.17 GAL/HR
FUEL PRESSURE AT F/M   400.7     PSIA     FUEL TEMP AT F/M          89.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   59.64 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            -2.03 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               7.13  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.552 %      O2  16.9-- %      CO     66.0 PPM      CHX      .0 PPM
 NO     22.5 PPM   NO2       6.0 PPM  NOX    29.4 PPM (NO(NDIR) + NO2(NDUV))
 NO     34.3 PPM   NO2       5.0 PPM  NOX    40.2 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=     6.46                   CHX=     .00
                    CHEMILUMINESCENCE NOX=   4.01.    NDIR + NDUV NOX=    3.50

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .012538
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:   98.0110 %
   CHECK ON F/A RATIO- F/A = .012210 W/O O2. CALCULATED O2 = 17.441 %

SMOKE INDEX: 18.66
SALTZMAN NOX = 31.9                    PPM
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Figure 280. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 78, READING #    892
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND. ON PRESSURE NOZZLE
TEST DATE:  8 -9-72                       READING WAS TAKEN AT 1309118 HOURS

CYCLE POINT  4                                          55 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.756 LB/SEC     AVG BURNER INLET TEMP    438. DEG F
AVG BURNER INLET PRES  71.5    PSIA       AVG BURNER OUTLET TEMP 1417. DEG F
AVG BURNER DELTA P      7.83    "HG       PRESSURE LOSS              5.38 %
OVERALL F/A RATIO      .01454  (F/P)      FUEL FLOW RATE           144.31 LB/HR
AIR LOAD FACTOR        1..498             PATTERN FACTOR           .35273
HOT HOT SPOT:  # 16 @ 1765.  DEG F        MAX BOT / AVG BOT        1.2457
FUEL INLET TEMPERATURE  92.  DEG F        FUEL INLET PRESSURE      386.8  PSIA
HEAT LOADING PARAMETER  .36813E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
          ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1363.  6 1273. 15 1664. 19 1421. 24 1552. 27 1399. 36 1522.
ANNULUS 2  4 1334.  7 1268. 16 1765. 21 1143. 25 1446. 34 1452. 37 1647.
ANNULUS 3  5 1218. 14 1581. 17 1697. 22 1172. 26 1343. 35 1343. 39 1153.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          71.44   PSIA     TOTAL PRESSURE         71.56   PSIA
STATIC PRESSURE         71.13   PSIA     STATIC PRESSURE        70.98   PSIA
VELOCITY DELTA P          .64    "HG     VELOCITY DELTA P        1.18    "HG
AIR TEMPERATURE          438.  DEG F     AIR TEMPERATURE         438.  DEG F
AIR VELOCITY          115.09 FT/SEC     AIR VELOCITY          150.38 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.256    "HG

AIR FLOW DATA: P-REF= 143.4 PSIA   DELTA P= 3.55 "HG   T-REF=  89. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       332.     HZ     VOLUMETRIC FLOW RATE  23.29 GAL/HR
FUEL PRESSURE AT F/M   346.8    PSIA     FUEL TEMP AT F/M           92.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    67.66 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                70.18 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   7.79  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   2.877 %     O2  19.388 %      CO    123.7 PPM     CHX       .2 PPM
 NO     31.6 PPM  NO2     10.6 PPM  NOX    42.2 PPM (NO(NDIR) + NO2(NDUV))
 NO     33.4 PPM  NO2      1.0 PPM  NOX    34.3 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   8.34                    CHX=    .02
                    CHEMILUMINESCENCE NOX=   3.88,   NDIR + NDUV NOX=    4.88

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .014229
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7884 %
   CHECK ON F/A RATIO- F/A = .013773 W/O O2, CALCULATED O2 = 18.883 %

SMOKE INDEX: 31.46
SALTZMAN NOX = 51.3                PPM
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Figure 281. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 78, READING #    893
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND, ON PRESSURE NOZZLE
TEST DATE: 8 -9-72                      READING WAS TAKEN AT 1332:19 HOURS

CYCLE POINT  3                                          75 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.919 LB/SEC    AVG BURNER INLET TEMP   473. DEG F
AVG BURNER INLET PRES  80.4    PSIA     AVG BURNER OUTLET TEMP 1583. DEG F
AVG BURNER DELTA P      8.70    "HG     PRESSURE LOSS             5.32 %
OVERALL F/A RATIO     .01681  (F/M)     FUEL FLOW RATE          176.69 LB/HR
AIR LOAD FACTOR        1.1896            PATTERN FACTOR          .32857
BOT HOT SPOT:  # 16 = 1939.  DEG F      MAX BOT / AVG BOT       1.2247
FUEL INLET TEMPERATURE  95.  DEG F      FUEL INLET PRESSURE      377.6  PSIA
HEAT LOADING PARAMETER  .39234E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1532.  6 1429. 15 1796. 19 1641. 24 1793. 27 1882. 36 1858.
ANNULUS 2  4 1582.  7 1455. 16 1939. 21 1298. 25 1684. 34 1661. 37 1883.
ANNULUS 3  5 1381. 14 1633. 17 1893. 22 1304. 26 1587. 35 1583. 39 1386.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          80.27   PSIA    TOTAL PRESSURE           80.45   PSIA
STATIC PRESSURE         79.59   PSIA    STATIC PRESSURE          80.23   PSIA
VELOCITY DELTA P         1.40    "HG    VELOCITY DELTA P           .44    "HG
AIR TEMPERATURE         473.  DEG F     AIR TEMPERATURE           473.  DEG F
AIR VELOCITY          166.23 FT/SEC     AIR VELOCITY             93.14 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))      -.351    "HG

AIR FLOW DATA: P-REF= 102.8 PSIA   DELTA P= 4.82 "HG    T-REF=  98. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       834.      HZ     VOLUMETRIC FLOW RATE  28.88 GAL/HR
FUEL PRESSURE AT F/M  645.4     PSIA     FUEL TEMP AT F/M             98.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   76.80 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            78.66 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               8.52  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    3.281 %      O2  13.800 %      CO    182.7 PPM      CHX       .6 PPM
 NO     46.4 PPM  NO2     15.6 PPM  NOX     62.1 PPM (NO(NDIR) + NO2(NDUV))
 NO     47.5 PPM  NO2      4.4 PPM  NOX     51.8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    8.92                   CHX=    .06
                  CHEMILUMINESCENCE NOX=  4.98,   NDIR + NDUV NOX=    5.98

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .016232
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7837 %
   CHECK ON F/A RATIO- F/A = .015589 W/O O2, CALCULATED O2 = 18.448 %

SMOKE INDEX: 52.70
SALTZMAN NOX = 65.3                   PPM
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Figure 282. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative 75% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 67, TEST SERIES 78, READING #    894
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND. ON PRESSURE NOZZLE
TEST DATE: 8 -9-72                         READING WAS TAKEN AT 135812Z HOURS

CYCLE POINT  2                                        100 % POWER SETTING

                        ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW           3.242 LB/SEC     AVG BURNER INLET TEMP    521. DEG F
AVG BURNER INLET PRES  92.3    PSIA        AVG BURNER OUTLET TEMP 1807. DEG F
AVG BURNER DELTA P      9.85    "HG        PRESSURE LOSS             5.24 %
OVERALL F/A RATIO     .01955  (F/M)        FUEL FLOW RATE          228.14 LB/HR
AIR LOAD FACTOR       1.0996               PATTERN FACTOR           .30711
BOT HOT SPOT:  # 16 = 2202.  DEG F         MAX BOT / AVG BOT       1.2186
FUEL INLET TEMPERATURE  96.  DEG F         FUEL INLET PRESSURE      538.3  PSIA
HEAT LOADING PARAMETER  .44088E+07 BTU/HOUR/ATM/CUBIC FOOT

                      **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1730.  6 1540. 15 2041. 19 1972. 24 2151. 27 1820. 36 1811.
ANNULUS 2   4 1642.  7 1638. 16 2202. 21 1480. 25 1949. 34 1874. 37 1971.
ANNULUS 3   5 1497. 14 1894. 17 2163. 22 1546. 26 1782. 35 1759. 39 1489.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           92.30    PSIA    TOTAL PRESSURE         92.37   PSIA
STATIC PRESSURE          92.15    PSIA    STATIC PRESSURE        91.56   PSIA
VELOCITY DELTA P           .30     "HG    VELOCITY DELTA P        1.65    "HG
AIR TEMPERATURE           521.  DEG F     AIR TEMPERATURE         521.  DEG F
AIR VELOCITY               .73 FT/SEC     AIR VELOCITY          172.43 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]           -.145    "HG

AIR FLOW DATA: P-REF= 102.4 PSIA    DELTA P= 4.99 "HG    T-REF=  89. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       850.      HZ     VOLUMETRIC FLOW RATE  36.92 GAL/HR
FUEL PRESSURE AT F/M   631.1     PSIA     FUEL TEMP AT F/M        97.  DEG F

                    ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    87.50 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             90.33 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                9.78  "HG (XDUCER # 13)

                         * CHEMICAL ANALYSIS RESULTS *
                         GAS SAMPLES TAKEN IN PLANE #1
CO2    3.867 %      O2  14.700 %      CO    114.3 PPM     CHX       .5 PPM
 NO     68.9 PPM  NO2     13.3 PPM   NOX     82.1 PPM [NO(NDIR) + NO2(NDUV)]
 NO     70.2 PPM  NO2       .0 PPM   NOX     70.2 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    6.76                 CHX=      .04
                 CHEMILUMINESCENCE NOX=   5.81,    NDIR + NDUV NOX=     6.80

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .019211
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6308 %
   CHECK ON F/A RATIO- F/A = .018399 W/O O2. CALCULATED O2 = 15.608 %

SMOKE INDEX: 62.08
SALTZMAN NOX = X                       PPM
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Figure 283. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative 100% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 78, READING #    897
T63 FINAL PRECHAMBER MOD "B"  RUN STD T63 INLET COND, ON PRESSURE NOZZLE
TEST DATE:  8 -9-72                      READING WAS TAKEN AT 1452: 9 HOURS

CYCLE POINT  7                                             0 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.823 LB/SEC    AVG BURNER INLET TEMP   296. DEG F
AVG BURNER INLET PRES  43.8   PSIA      AVG BURNER OUTLET TEMP  406. DEG F
AVG BURNER DELTA P      4.63    "HG      PRESSURE LOSS             5.19 %
OVERALL F/A RATIO     .00215  (F/M)     FUEL FLOW RATE           14.12 LB/HR
AIR LOAD FACTOR        1.1427            PATTERN FACTOR          .26137
BOT HOT SPOT:  # 16 =  435.  DEG F      MAX BOT / AVG BOT       1.0708
FUEL INLET TEMPERATURE  90.  DEG F      FUEL INLET PRESSURE       42.0  PSIA
HEAT LOADING PARAMETER  .57441E+06 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  396.   6  395. 15  428. 19  404. 24  428. 27  420. 36  423.
ANNULUS 2   4  391.   7  400. 16  435. 21  390. 25  414. 34  405. 37  408.
ANNULUS 3   5  375.  14  407. 17  429. 22  395. 26  393. 35  406. 39  383.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           43.83   PSIA    TOTAL PRESSURE          43.87   PSIA
STATIC PRESSURE          43.58   PSIA    STATIC PRESSURE         43.66   PSIA
VELOCITY DELTA P           .50    "HG    VELOCITY DELTA P          .43    "HG
AIR TEMPERATURE          296.  DEG F     AIR TEMPERATURE         296.  DEG F
AIR VELOCITY           121.19 FT/SEC     AIR VELOCITY           112.22 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.085    "HG

AIR FLOW DATA: P-REF= 105.5 PSIA   DELTA P= 1.52 "HG   T-REF=  90. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        47.      HZ    VOLUMETRIC FLOW RATE    2.27 GAL/HR
FUEL PRESSURE AT F/M  307.4    PSIA    FUEL TEMP AT F/M          90.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   41.58 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             42.96 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.59  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX =X                    PPM
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Figure 284. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Nonregenerative Lean Blow Out.

TABLE LXXVI. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE FOR (1) CONVENTIONAL LINER, (2) FINAL PRECHAMBER MODIFICATION "B" LINER OPERATING ON WALL FUEL FILM, AND (3) FINAL PRECHAMBER MODIFICATION "B" LINER OPERATING ON PRESSURE ATOMIZER

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	893	652	496	383	214	75
H/C, (ppm)	100	37	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
NO_x, (Saltzman) (ppm)	18.5	27.8	37.6	45.9	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Final Prechamber, Mod. "B" - Wall Film						NO DATA TAKEN
A. Emissions						
CO, (ppm)	619.2	289.6	127.5	166.8	175.0	
H/C, (ppm)	140.0	40.0	9.8	7.2	2.1	
NO_x, (On-Line, NDIR & NDUV) (ppm)	12.2	17.3	27.1	35.5	51.6	
NO_x, (On-Line, CL) (ppm)	12.0	18.3	27.5	41.1	52.9	
NO_x, (Saltzman) (ppm)	10.4	19.6	30.3	39.9	55.9	
Smoke Number	0.10	1.82	0.96	0.11	3.26	
B. Pressure Loss (%)	5.98	5.15	5.92	5.79	5.81	
C. Temp. Profile (T_{max}/T_{avg})	1.441	1.357	1.277	1.290	1.274	
III. Final Prechamber, Mod. "B" - Pressure Atomizer						
A. Emissions						
CO, (ppm)	156.7	97.2	86.8	123.7	152.7	114.3
H/C, (ppm)	13.0	2.4	.8	.2	.6	.5
NO_x, (On-Line, NDIR & NDUV) (ppm)	11.7	19.6	29.4	42.2	62.1	82.1
NO_x, (On-Line, CL) (ppm)	10.8	19.3	40.2	34.3	51.9	70.2
NO_x, (Saltzman) (ppm)	16.3	21.7	31.9	51.3	65.3	-
Smoke Number	7.13	14.11	18.66	31.46	52.70	62.08
B. Pressure Loss (%)	5.70	5.73	5.66	5.38	5.32	5.24
C. Temp. Profile (T_{max}/T_{avg})	1.244	1.232	1.230	1.246	1.225	1.219

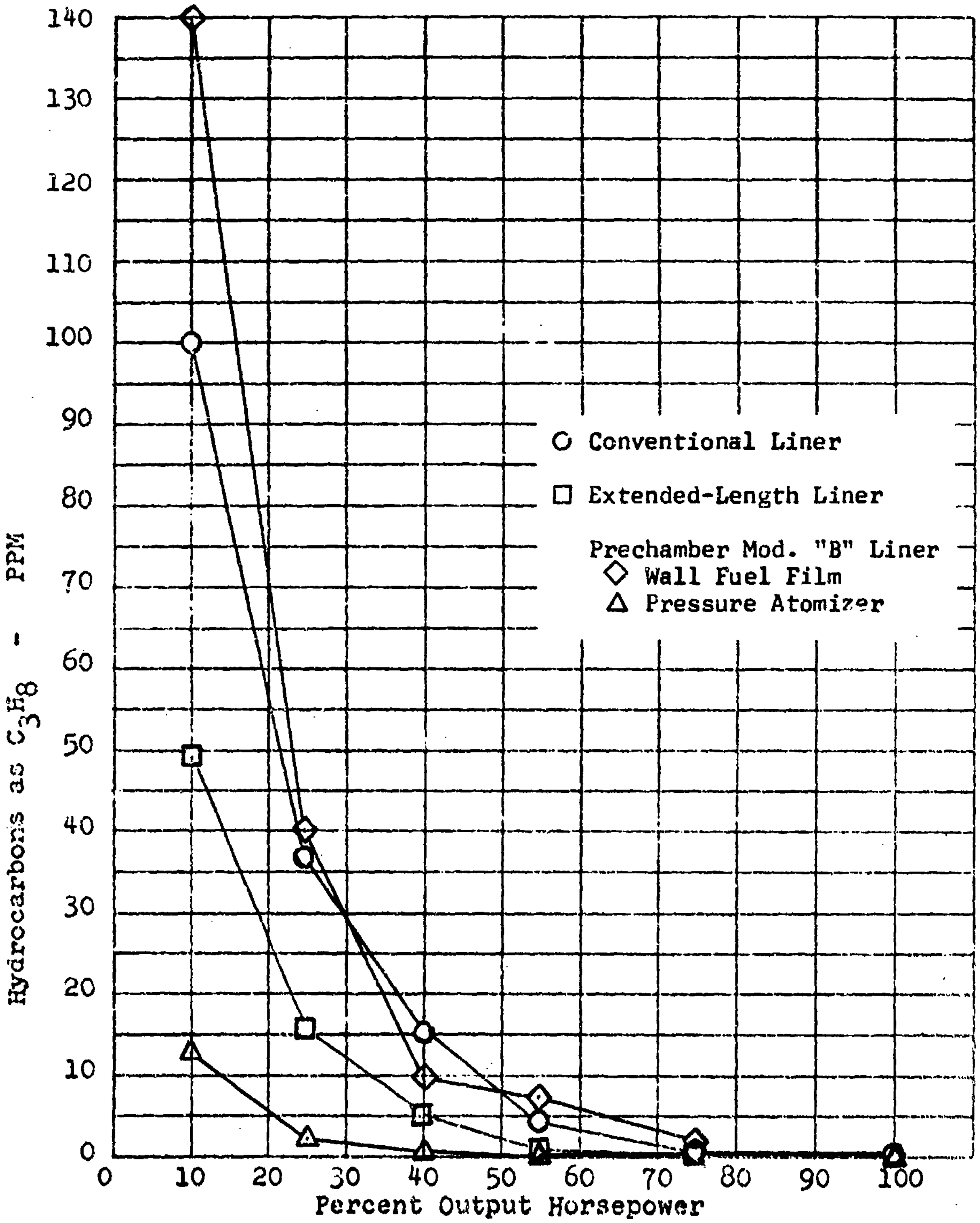

Figure 285. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Prechamber Final Design, Modification "B" Combustor and T63 Baseline Combustors.

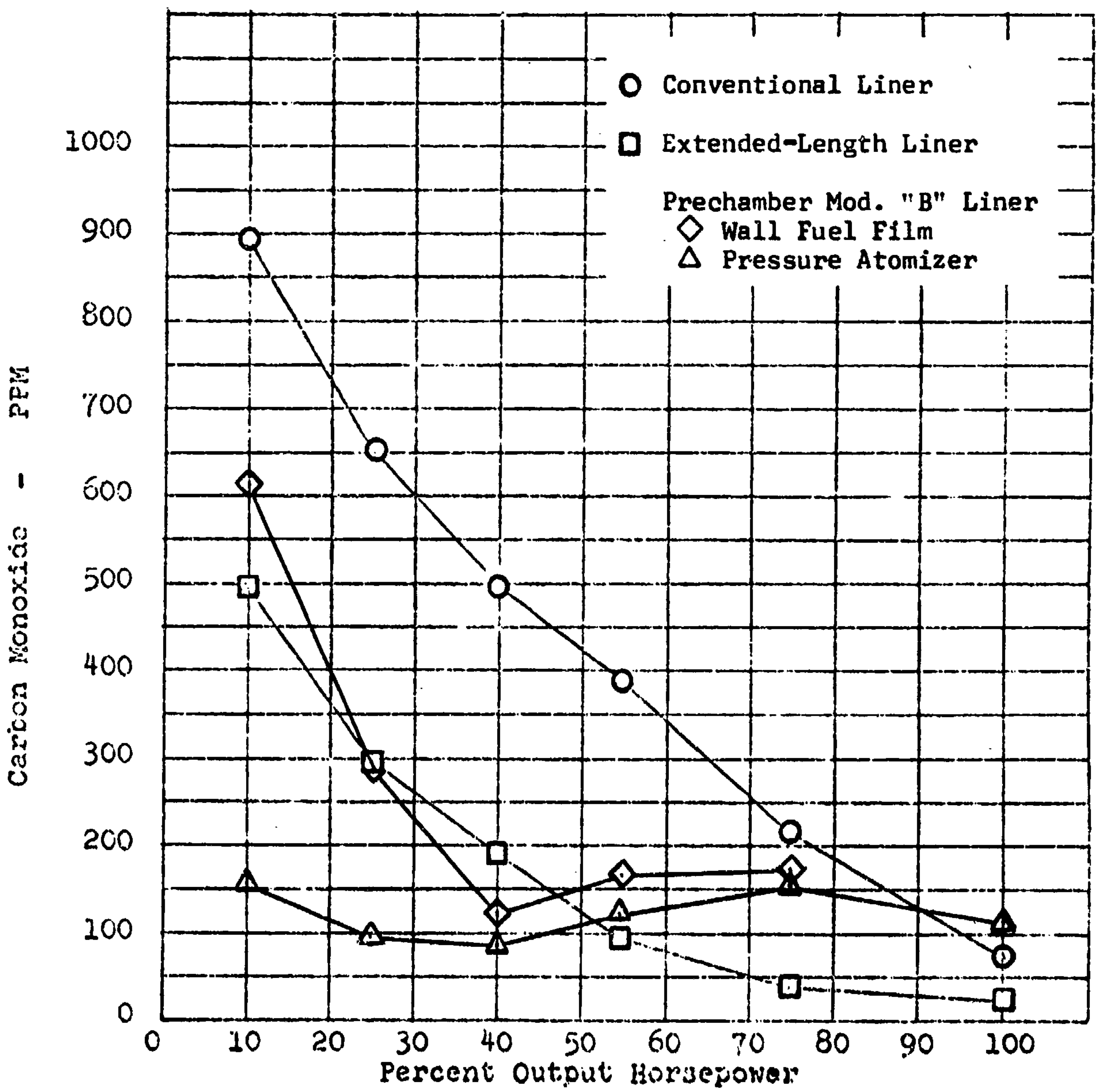

Figure 286. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Prechamber Final Design, Modification "B" Combustor and T63 Baseline Combustors.

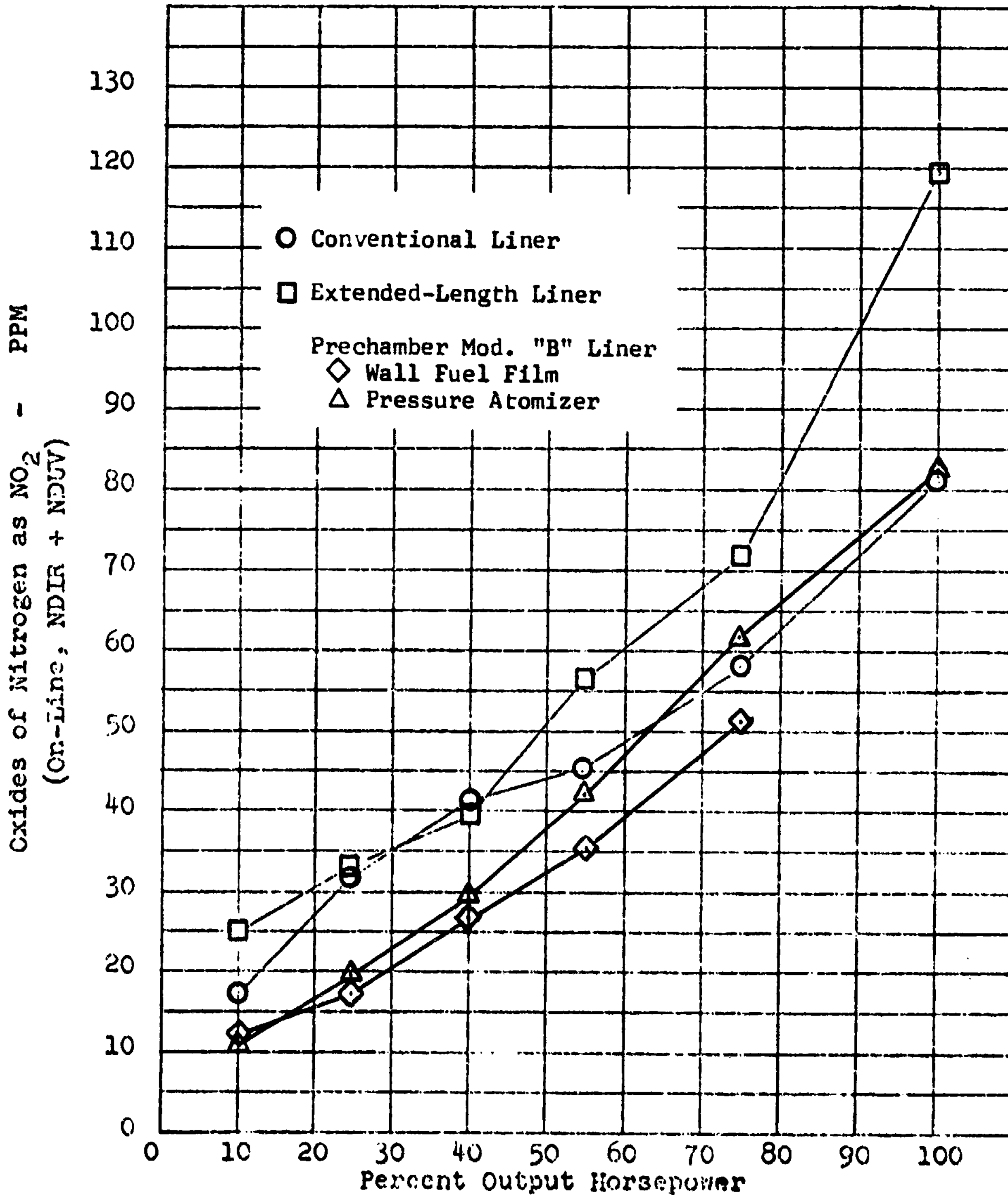

Figure 287. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber Final Design, Modification "B" Combustor and T63 Baseline Combustors.

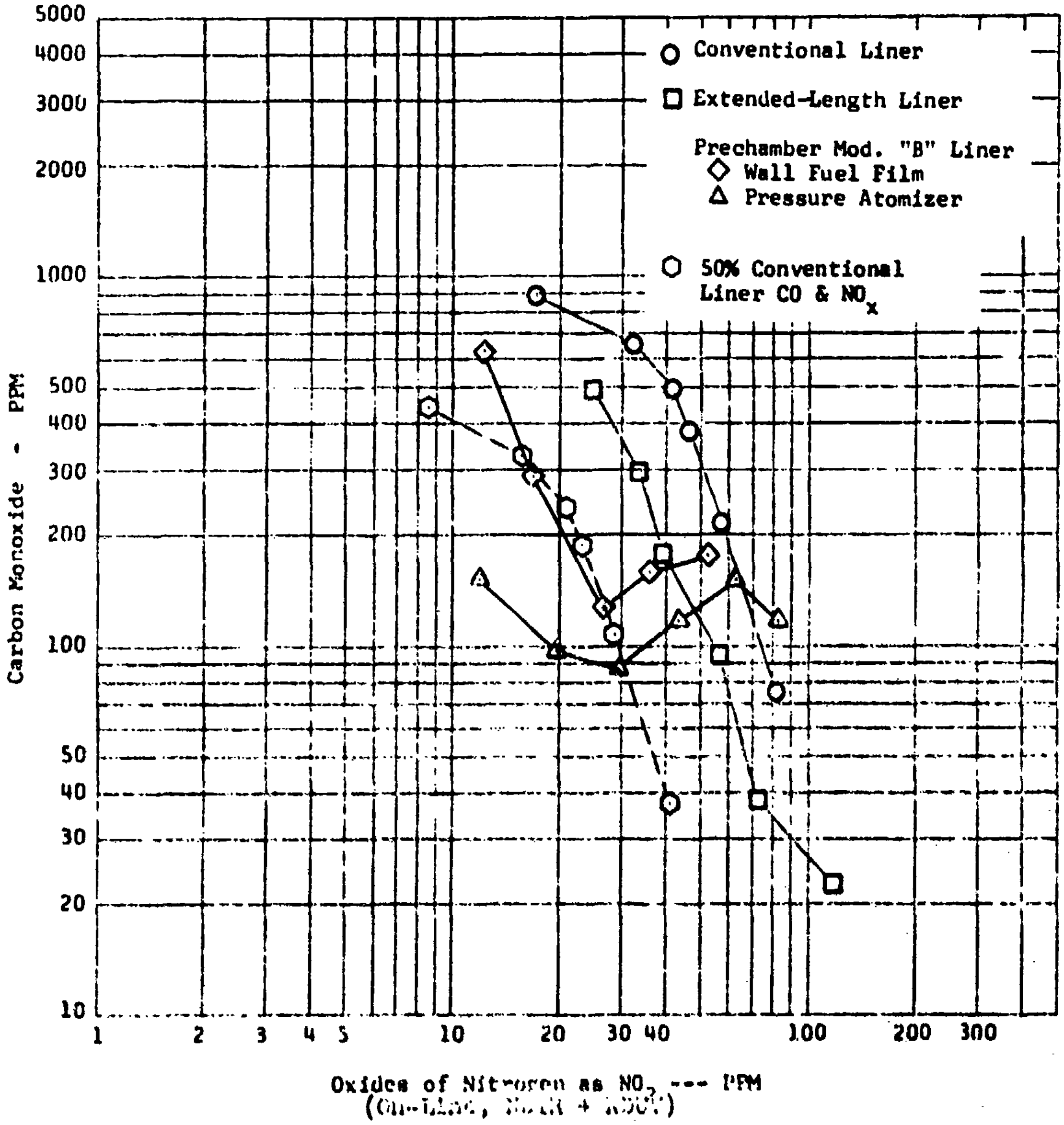

Figure 288. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber Final Design, Modification "B" Combustor and T63 Baseline Combustors.

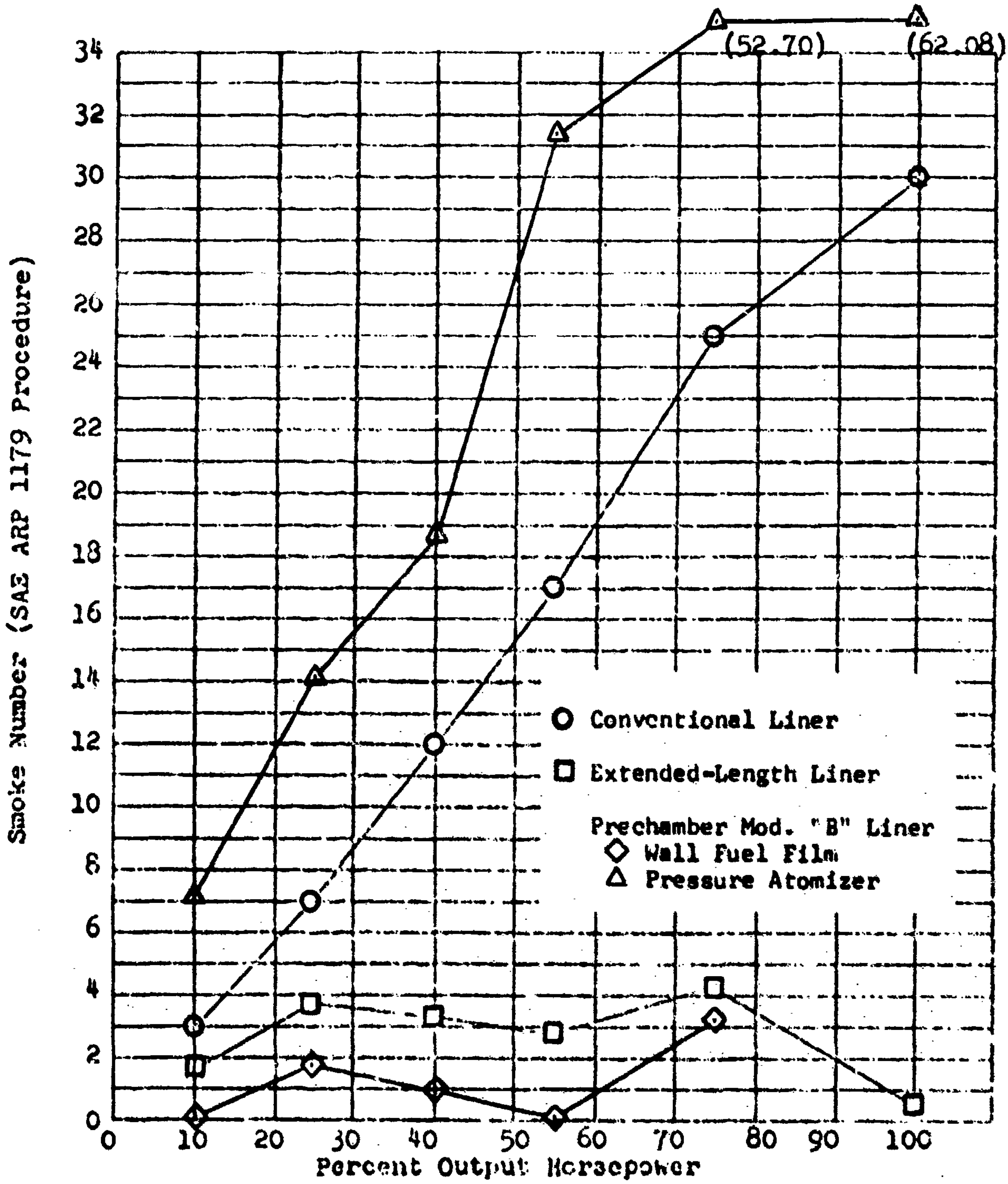

Figure 289. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended Length, Prechamber Final Design, Modification "B" Combustor and T63 Baseline Combustors.

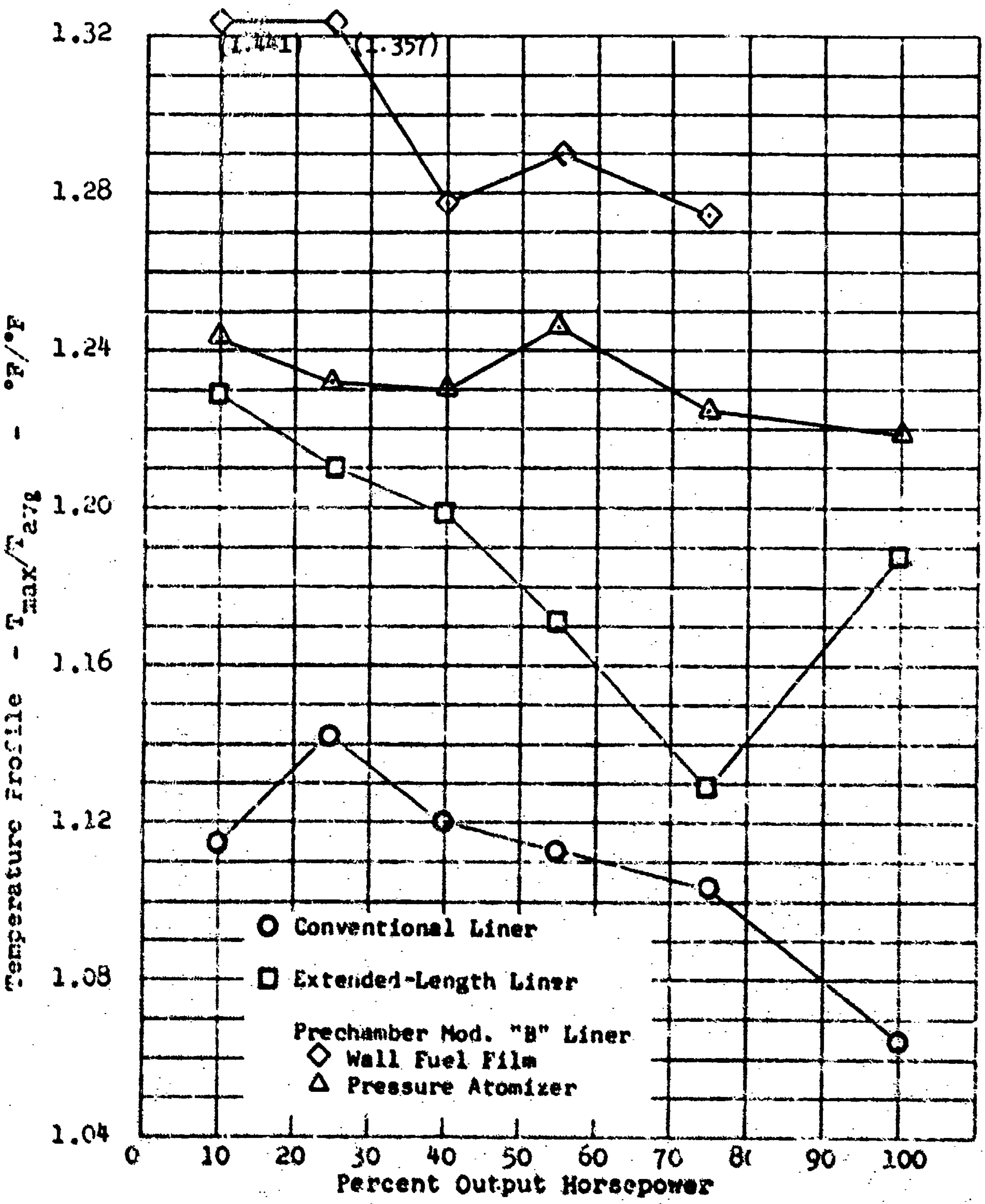

Figure 290. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length Prechamber Final Design, Modification "B" Combustor and T63 Baseline Combustors.

occurred at a fuel-air ratio of 0.0086. Under pressure atomizer operation, the test was terminated when the fuel-air ratio dropped below 0.00215. Skin temperature profiles for the Modification "B" combustor are plotted in Figures 291 and 292 for the two fuel modes.

Since this was the last "Final Prechamber Combustor" tested on a pressure atomizer fuel system, the emission results for this fuel injection mode can be summarized. Shown in Table LXXVII are the computed emission index values for all three pressure atomizing "Final Prechamber Combustor Liners". It is evident that the "best" overall configuration was Modification "A", which provided a 55% reduction in total emissions with no increase in any individual constituent.

The Final Prechamber Modification "B" combustor was tested in both fuel injection modes at regenerative T63 operating conditions. The test results for both fuel modes are shown in Figures 293 through 306. The combustor was unable to sustain combustion at the regenerative idle fuel/air ratio when operating on the wall fuel film mode. The lowest ratio that would support combustion was 0.0089 fuel/air. In order to obtain the idle fuel/air ratio, the pressure atomizer nozzle, because of its extremely low lean blowout capability, was operated as pilot. With the pilot burning, the wall film system was able to extend its operation to the regenerative idle conditions.

Combustor emission index values for a regenerative T63 engine operating over the LOH duty cycle are given in Table LXXVIII for the Final Prechamber Modification "B" combustor liner and the nonregenerative and regenerative combustor liners operating at regenerative conditions. Relative regenerative engine emissions are listed in Table LXXIX. Compared to the nonregenerative T63 liner, the Final Prechamber Modification "B" combustor produced 31% fewer total emissions when operated in the wall film mode, and 44% fewer mass emissions on the pressure atomizer. Each Prechamber mode, however, greatly exceeded the baseline in the magnitude of one constituent emission. The wall fuel film mode produced nearly six times the baseline hydrocarbons, and the pressure atomizer mode produced over eleven times as much smoke/particulates.

For the ambient temperature and pressure startup test on the Prechamber Modification "B" combustor, a special electrical spark igniter was inserted into the combustor liner through the torch igniter hole. This igniter position was 0.7 inch downstream of the reaction-zone holes. The burner test conditions were:

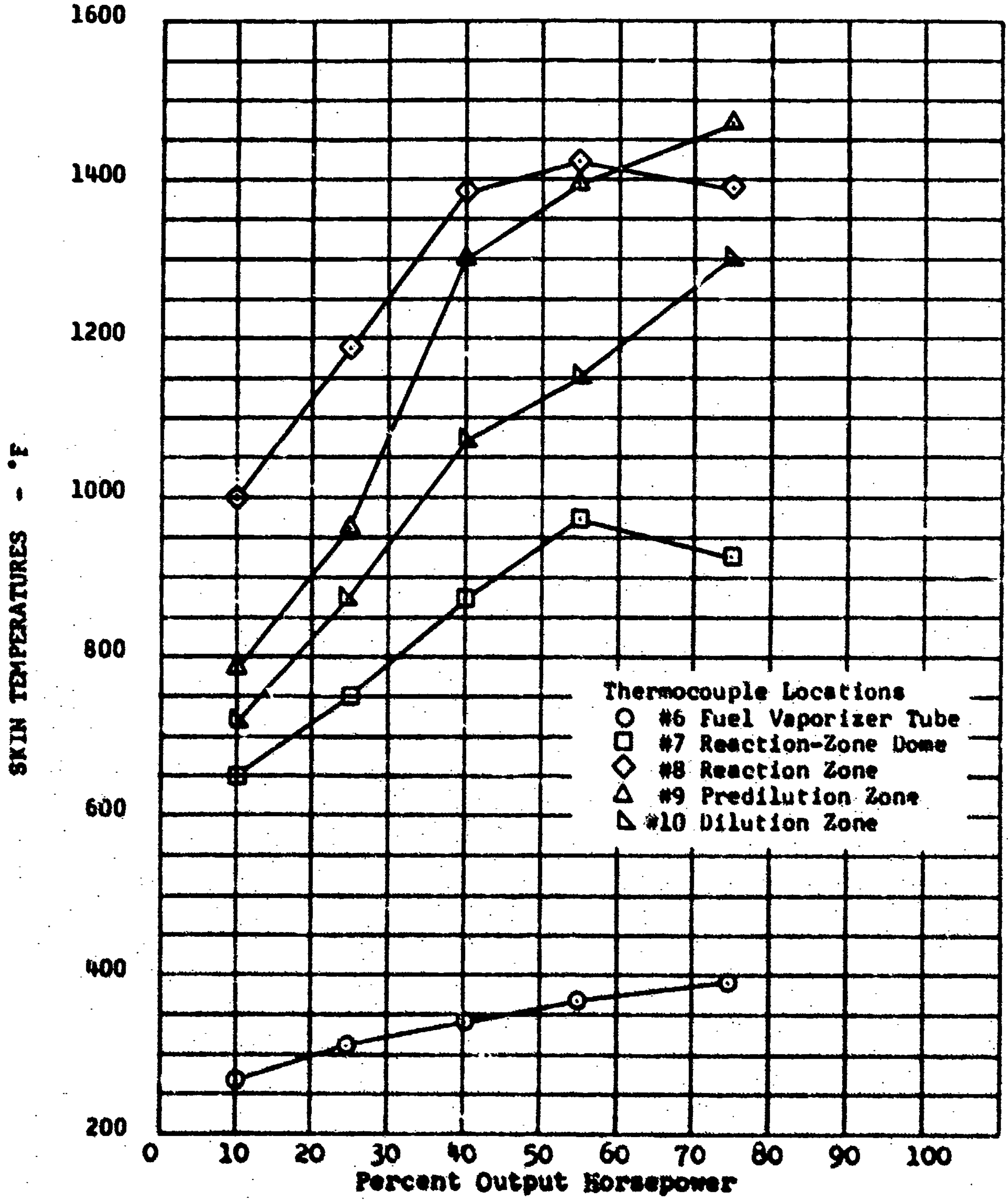

Figure 291. Nonregenerative T63-A-5A Combustor Skin Temperatures for Prechamber Final Design Combustor Modification "B" Operating on Wall Fuel Film Injection.

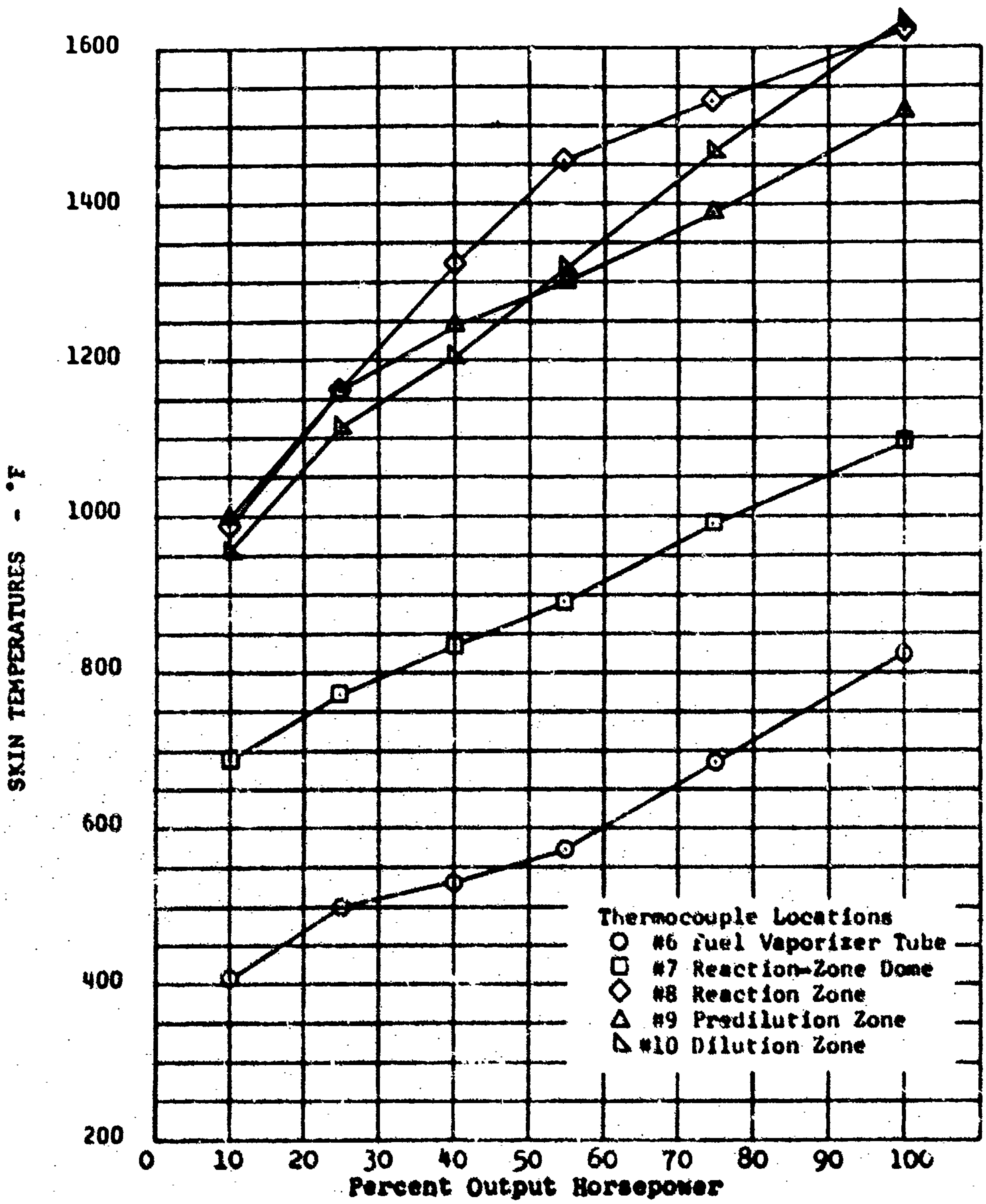

Figure 292. Nonregenerative T63-A-5A Combustor
Skin Temperatures for Prechamber
Final Design Combustor Modification "B" Operating
on Pressure Atomizer Injection.

TABLE LXXVII. EMISSION INDEX SUMMARY FOR T63 BASELINE AND FINAL PRECHAMBER COMBUSTORS

Combustor Tested	C_xH_y	CO	NO_x	Particu-lates	Total Emissions
EMISSION INDEX (lb/1000 lb fuel)					
• Baseline	1.544	26.094	5.068	.239	32.945
• Final Prechamber-Pressure Atomizer					
Initial Design	.039	10.608	4.611	.128	15.386
Modification "A"	.025	10.292	4.300	.086	14.703
Modification "B"	.180	8.415	4.762	.902	14.259
RELATIVE EMISSION INDEX (%)					
• Baseline	100	100	100	100	100
• Final Prechamber-Pressure Atomizer					
Initial Design	2	41	91	54	47
Modification "A"	2	39	85	36	45
Modification "B"	12	32	94	377	43

```
T63 COMBUSTOR EXPERIMENTS - RIG E/U 67, TEST SERIES 70, READING #     898
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-18-72                           READING WAS TAKEN AT 1318127 HOURS

CYCLE POINT  1                                                 10 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW           1.775 LB/SEC    AVG BURNER INLET TEMP    667. DEG F
AVG BURNER INLET PRES  43.9     PSIA      AVG BURNER OUTLET TEMP  1240. DEG F
AVG BURNER DELTA P      7.13     "HG      PRESSURE LOSS             7.08 %
OVERALL F/A RATIO      .00869   (F/P)     FUEL FLOW RATE           56.01 LB/HR
AIR LOAD FACTOR        1.3575             PATTERN FACTOR           .36338
BOT HOT SPOT:  # 16 = 1448.   DEG F       MAX BOT / AVG BOT        1.1679
FUEL INLET TEMPERATURE 106.   DEG F       FUEL INLET PRESSURE       38.8   PSIA
HEAT LOADING PARAMETER  .33492E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1170.  6 1145. 15 1385. 19 1331. 24 1326. 27 1239. 36 1323.
ANNULUS 2   4 1168.  7 1147. 16 1448. 21 1136. 25 1259. 34 1228. 37 1307.
ANNULUS 3   5 1084. 14 1207. 17 1417. 22 1141. 26 1164. 35 1201. 39 1101.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          43.86   PSIA     TOTAL PRESSURE          43.93   PSIA
STATIC PRESSURE         43.51   PSIA     STATIC PRESSURE         43.60   PSIA
VELOCITY DELTA P         .72     "HG     VELOCITY DELTA P          .60    "HG
AIR TEMPERATURE         667.   DEG F     AIR TEMPERATURE          667.  DEG F
AIR VELOCITY          177.33 FT/SEC      AIR VELOCITY           172.00 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.140    "HG

AIR FLOW DATA: P-REF= 149.8 PSIA   DELTA P= 1.45 "HG   T-REF= 86. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY     210.      HZ      VOLUMETRIC FLOW RATE    9.14 GAL/HR
FUEL PRESSURE AT F/M  253.3    PSIA      FUEL TEMP AT F/M         87.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     40.39 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              42.72 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 7.06 "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    1.721 %     O2   18.300 %     CO    209.6 PPM     CHX    31.0 PPM
NO       6.3 PPM   NO2     1.6 PPM   NOX     7.9 PPM (NO(NDIR) + NO2(NDUV))
NO       4.7 PPM   NO2      .6 PPM   NOX     5.3 PPM ( CHEMILUMINESCENCE  )
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 23.08                       CHX=   9.36
              CHEMILUMINESCENCE NOX=     .96,    NDIR + NDUV NOX=        1.42

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .008509
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:   98.8484 %
  CHECK ON F/A RATIO- F/A = .008394 W/O O2, CALCULATED O2 = 18.808 %

SMOKE INDEX:  .44
SALTZMAN NOX =  3.99           PPM
-------------------------------------------------------------------------
REMARKS:
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Film Nozzle

Not True Idle F/A

Figure 293. Final Prechamber Liner Modification "B" on Wall Film Injection at Regenerative 10% Power, High F/A.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #     899
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-10-72                         READING WAS TAKEN AT 1349:25 HOURS

CYCLE POINT  1                                              10 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW           1.772 LB/SEC     AVG BURNER INLET TEMP    668. DEG F
AVG BURNER INLET PRES   44.0     PSIA      AVG BURNER OUTLET TEMP 1243. DEG F
AVG BURNER DELTA P       6.68     "HG      PRESSURE LOSS             7.46 %
OVERALL F/A RATIO       .00885   (F/P)     FUEL FLOW RATE           56.44 LB/HR
AIR LOAD FACTOR         1.3541             PATTERN FACTOR           .29156
BOT HOT SPOT: # 16 = 1411.  DEG F          MAX BOT / AVG BOT        1.1348
FUEL INLET TEMPERATURE  90.  DEG F         FUEL INLET PRESSURE     178.3  PSIA
HEAT LOADING PARAMETER   .22914E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1161.  6 1129. 15 1377. 19 1293. 24 1378. 27 1271. 36 1312.
ANNULUS 2   3 1200.  7 1142. 16 1411. 21 1146. 25 1296. 34 1267. 37 1317.
ANNULUS 3   5 1084. 14 1291. 17 1395. 22 1148. 26 1201. 35 1204. 39 1089.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          43.93    PSIA    TOTAL PRESSURE         43.57   PSIA
STATIC PRESSURE         43.55    PSIA    STATIC PRESSURE        43.47   PSIA
VELOCITY DELTA P          .78    "HG     VELOCITY DELTA P        1.03    "HG
AIR TEMPERATURE          668.  DEG F     AIR TEMPERATURE         668.  DEG F
AIR VELOCITY           185.08 FT/SEC     AIR VELOCITY          212.28 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.086   "HG

AIR FLOW DATA: P-REF= 105.6 PSIA   DELTA P= 1.45 "HG    T-REF=  97. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      209.      HZ     VOLUMETRIC FLOW RATE    9.10 GAL/HR
FUEL PRESSURE AT F/M   300.7    PSIA     FUEL TEMP AT F/M         90.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     40.67 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              42.56 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.63 "HG  (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2   1.817 %    O2  17.600 %     CO     98.2 PPM     CHX      .8 PPM
 NO    19.7 PPM  NO2     4.8 PPM  NOX    24.5 PPM [NO(NDIR) + NO2(NDUV)]
 NO    21.1 PPM  NO2      .5 PPM  NOX    21.6 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.82                CHX=     .15
              CHEMILUMINESCENCE NOX=   3.91,   NDIR + NDUV NOX=     4.44

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .009124
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7174 %
  CHECK ON F/A RATIO- F/A = .008753 W/O O2, CALCULATED O2 = 18.462 %

SMOKE INDEX:  12.5
SALTZMAN NOX =  270           PPM
-------------------------------------------------------------------------
REMARKS:  Pressure Nozzle

          Not True Idle F/A
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Figure 294. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 10% Power, High F/A.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #    980
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-10-72                        READING WAS TAKEN AT 1407:38 HOURS

CYCLE POINT  1                                              10 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.766 LB/SEC     AVG BURNER INLET TEMP    668. DEG F
AVG BURNER INLET PRES   43.6    PSIA      AVG BURNER OUTLET TEMP  1188. DEG F
AVG BURNER DELTA P       6.86    "HG      PRESSURE LOSS             7.73 %
OVERALL F/A RATIO       .00799  (F/P)     FUEL FLOW RATE           50.77 LB/HR
AIR LOAD FACTOR         1.3607            PATTERN FACTOR           .27404
BOT HOT SPOT:  # 16 = 1330.   DEG F       MAX BOT / AVG BOT        1.1199
FUEL INLET TEMPERATURE   91.   DEG F      FUEL INLET PRESSURE      150.2   PSIA
HEAT LOADING PARAMETER  .20782E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1113.   6 1385. 15 1287. 19 1282. 24 1309. 27 1243. 36 1254.
ANNULUS 2   4 1149.   7 1490. 16 1330. 21 1106. 25 1241. 34 1183. 37 1255.
ANNULUS 3   5 1053.  14 1185. 17 1325. 22 1119. 26 1156. 35 1140. 39 1047.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          43.53    PSIA    TOTAL PRESSURE          43.65   PSIA
STATIC PRESSURE         43.20    PSIA    STATIC PRESSURE         43.32   PSIA
VELOCITY DELTA P          .68    "HG     VELOCITY DELTA P          .67   "HG
AIR TEMPERATURE         668.   DEG F     AIR TEMPERATURE         668.  DEG F
AIR VELOCITY           172.96 FT/SEC     AIR VELOCITY           171.71 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.228   "HG

AIR FLOW DATA: P-REF= 145.3 PSIA   DELTA P= 1.45 "HG   T-REF=  98. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       188.     HZ     VOLUMETRIC FLOW RATE     8.19 GAL/HR
FUEL PRESSURE AT F/M    392.5    PSIA    FUEL TEMP AT F/M          91.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    40.22 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             42.42 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.74  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    1.625 %     O2   17.700 %     CO    150.8 PPM     CHX       2.2 PPM
NO      14.1 PPM   NO2      5.6 PPM  NOX     19.7 PPM (NO(NDIR) + NO2(NDUV))
NO      16.1 PPM   NO2      3.5 PPM  NOX     19.6 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  18.40                  CHX=      .42
                 CHEMILUMINESCENCE NOX=   3.93,   NDIR + NDUV NOX=     3.95

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .008270
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.5136 %
   CHECK ON F/A RATIO- F/A = .007870 W/O O2, CALCULATED O2 = 18.724 %

SMOKE INDEX:  13.4
SALTZMAN NOX =  21.8              PPM
------------------------------------------------------------------------------
REMARKS:  Pressure Nozzle
```

Figure 295. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #     001
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-10-72                              READING WAS TAKEN AT 143515 HOURS

CYCLE POINT  1                                                  10 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.762 LB/SEC     AVG BURNER INLET TEMP   667. DEG F
AVG BURNER INLET PRES   43.5   PSIA       AVG BURNER OUTLET TEMP 1148. DEG F
AVG BURNER DELTA P       5.67   "HG       PRESSURE LOSS             7.76 %
OVERALL F/A RATIO       .00800  (F/A)     FUEL FLOW RATE           50.71 LB/HR
AIR LOAD FACTOR         1.3609            PATTERN FACTOR          .27160
BOT HOT SPOT:  # 16 = 1279.  DEG F        MAX BOT / AVG BOT       1.1135
FUEL INLET TEMPERATURE  91.   DEG F       FUEL INLET PRESSURE      57.3   PSIA
HEAT LOADING PARAMETER  .20623E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1091.  6 1071. 15 1245. 19 1142. 24 1213. 27 1151. 36 1272.
ANNULUS 2    4 1113.  7 1093. 16 1279. 21 1040. 25 1150. 34 1167. 37 1256.
ANNULUS 3    5 1021. 14 1216. 17 1264. 22 1048. 26 1083. 35 1138. 39 1063.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE           43.41   PSIA     TOTAL PRESSURE           43.51   PSIA
STATIC PRESSURE          42.98   PSIA     STATIC PRESSURE          43.20   PSIA
VELOCITY DELTA P          .89    "HG      VELOCITY DELTA P          .63    "HG
AIR TEMPERATURE          667.   DEG F     AIR TEMPERATURE          667.   DEG F
AIR VELOCITY           197.88 FT/SEC      AIR VELOCITY           166.19 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]            -.194   "HG

AIR FLOW DATA: P-REF= 105.3 PSIA   DELTA P= 1.44 "HG   T-REF=  98. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      188.     HZ      VOLUMETRIC FLOW RATE   8.19 GAL/HR
FUEL PRESSURE AT F/M   304.1   PSIA      FUEL TEMP AT F/M        92.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   40.08 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            42.06 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               6.77  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   1.530 %     O2  17.700 %    CO   407.1 PPM     CHX  140.0 PPM
 NO     4.9 PPM  NO2     2.4 PPM  NOX     7.3 PPM [NO(NDIR) + NO2(NDUV)]
 NO     2.5 PPM  NO2     1.9 PPM  NOX     4.4 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  49.52                  CHX=  26.86
                 CHEMILUMINESCENCE NOX=   .89,   NDIR + NDUV NOX=   1.46

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .007738
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  95.9246 %
   CHECK ON F/A RATIO- F/A = .007738 W/O O2, CALCULATED O2 = 18.840 %

SMOKE INDEX: X
SALTZMAN NOX = X                 PPM
--------------------------------------------------------------------------
REMARKS: Run both Film & Pressure Nozzles
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Figure 296. Final Prechamber Liner Modification "B" on Wall Film Injection at Regenerative 10% Power.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #     982
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-10-72                          READING WAS TAKEN AT 1500:56 HOURS

CYCLE POINT  6                                            25 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.073 LB/SEC    AVG BURNER INLET TEMP    702. DEG F
AVG BURNER INLET PRES  51.4    PSIA      AVG BURNER OUTLET TEMP 1272. DEG F
AVG BURNER DELTA P      6.43    "HG      PRESSURE LOSS             8.86 %
OVERALL F/A RATIO      .00874  (F/F)     FUEL FLOW RATE           65.21 LB/HR
AIR LOAD FACTOR        1.3748            PATTERN FACTOR           .35044
BOT HOT SPOT:  # 16 = 1472.  DEG F       MAX BOT / AVG BOT        1.1571
FUEL INLET TEMPERATURE 150.  DEG F       FUEL INLET PRESSURE      49.0   PSIA
HEAT LOADING PARAMETER  .22651E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1206.  6 1174. 15 1440. 19 1341. 24 1349. 27 1264. 36 1356.
ANNULUS 2    4 1211.  7 1192. 16 1472. 21 1165. 25 1271. 34 1256. 37 1336.
ANNULUS 3    5 1119. 14 1396. 17 1441. 22 1169. 26 1197. 35 1226. 39 1131.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE            51.33   PSIA    TOTAL PRESSURE           51.43   PSIA
STATIC PRESSURE           51.04   PSIA    STATIC PRESSURE          50.99   PSIA
VELOCITY DELTA P            .59   "HG     VELOCITY DELTA P           .88   "HG
AIR TEMPERATURE           702.  DEG F     AIR TEMPERATURE          702.  DEG F
AIR VELOCITY            150.39 FT/SEC     AIR VELOCITY           183.87 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.188    "HG

AIR FLOW DATA: P-REF= 105.0 PSIA   DELTA P= 2.00 "HG   T-REF=  98. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        242.      HZ    VOLUMETRIC FLOW RATE  10.54 GAL/HR
FUEL PRESSURE AT F/M    291.4     PSIA    FUEL TEMP AT F/M         94.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     47.24 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              50.17 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 8.33  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    1.673 %     O2  17.500 %     CO    166.8 PPM     CHX     34.0 PPM
 NO      3.4 PPM  NO2      1.6 PPM  NOX      5.0 PPM (NO(NDIR) + NO2(NDUV))
 NO      3.0 PPM  NO2       .6 PPM  NOX      3.6 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  18.61                 CHX=   5.97
                 CHEMILUMINESCENCE NOX=    .67,    NDIR + NDUV NOX=    .92

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .008622
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.8737 %
   CHECK ON F/A RATIO- F/A = .008150 W/O O2, CALCULATED O2 = 18.659 %

SMOKE INDEX:  .23
SALTZMAN NOX =  3.80          PPM
-----------------------------------------------------------------------------
REMARKS:   Film Nozzle
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Figure 297. Final Prechamber Liner Modification "B" on Wall Film Injection at Regenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 67, TEST SERIES 79, READING #     983
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-10-72                          READING WAS TAKEN AT 1518:37 HOURS

CYCLE POINT  6                                            25 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.056 LB/SEC    AVG BURNER INLET TEMP    701. DEG F
AVG BURNER INLET PRES   51.6    PSIA     AVG BURNER OUTLET TEMP  1279. DEG F
AVG BURNER DELTA P       8.37    "HG     PRESSURE LOSS              7.97 %
OVERALL F/A RATIO      .00884   (F/M)    FUEL FLOW RATE            65.45 LB/HR
AIR LOAD FACTOR         1.3572           PATTERN FACTOR            .31087
BOT HOT SPOT:  # 16 = 1459.   DEG F      MAX BOT / AVG BOT         1.1404
FUEL INLET TEMPERATURE   95.   DEG F     FUEL INLET PRESSURE       190.9   PSIA
HEAT LOADING PARAMETER   .22627E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1197.  6 1156. 15 1462. 19 1334. 24 1408. 27 1306. 36 1385.
ANNULUS 2   4 1234.  7 1168. 16 1459. 21 1175. 25 1318. 34 1267. 37 1388.
ANNULUS 3   5 1129. 14 1266. 17 1426. 22 1186. 26 1237. 35 1247. 39 1172.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE           51.57    PSIA   TOTAL PRESSURE            51.67    PSIA
STATIC PRESSURE          51.19    PSIA   STATIC PRESSURE           51.26    PSIA
VELOCITY DELTA P           .77     "HG   VELOCITY DELTA P            .83     "HG
AIR TEMPERATURE           701.   DEG F   AIR TEMPERATURE            701.   DEG F
AIR VELOCITY            171.43 FT/SEC    AIR VELOCITY             177.51 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]            -.195     "HG

AIR FLOW DATA: P-REF= 104.8 PSIA    DELTA P= 1.97 "HG    T-REF=  98. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       243.      HZ    VOLUMETRIC FLOW RATE   10.58 GAL/HR
FUEL PRESSURE AT F/M   313.9     PSIA    FUEL TEMP AT F/M          95.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE      47.50 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                50.26 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   8.28  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   1.793 %     O2   17.400 %     CO     62.0 PPM     CHX      .8 PPM
 NO    24.6 PPM   NO2     4.0 PPM   NOX    28.6 PPM [NO(NDIR) + NO2(NDUV)]
 NO    22.6 PPM   NO2      .0 PPM   NOX    22.6 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    6.84                CHX=    .15
                  CHEMILUMINESCENCE NOX=   4.09,    NDIR + NDUV NOX=   5.19

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .009093
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8835 %
   CHECK ON F/A RATIO- F/A = .008622 W/O O2, CALCULATED O2 = 18.499 %

SMOKE INDEX:  23.04
SALTZMAN NOX =  30.8             PPM
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REMARKS: Pressure Nozzle
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Figure 298. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 07, TEST SERIES 79, READING #    984
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-10-72                          READING WAS TAKEN AT 1667: 3 HOURS

CYCLE POINT  5                                              40 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.442 LB/SEC     AVG BURNER INLET TEMP    97. DEG F
AVG BURNER INLET PRES    59.2    PSIA     AVG BURNER OUTLET TEMP 1328. DEG F
AVG BURNER DELTA P       9.95     "HG     PRESSURE LOSS              8.25 %
OVERALL F/A RATIO      .00948   (F/M)     FUEL FLOW RATE          83.31 LB/HR
AIR LOAD FACTOR        1.4102             PATTERN FACTOR          .15894
BOT HOT SPOT:  # 16 = 1523.  DEG F        MAX BOT / AVG BOT       1.1473
FUEL INLET TEMPERATURE  97.  DEG F        FUEL INLET PRESSURE     208.5  PSIA
HEAT LOADING PARAMETER  .25101E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
          ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1246.  6 1209. 15 1474. 19 1401. 24 1454. 27 1365. 36 1419.
ANNULUS 2  4 1283.  7 1232. 16 1523. 21 1289. 25 1357. 34 1309. 37 1422.
ANNULUS 3  5 1170. 14 1350. 17 1504. 22 1228. 26 1289. 35 1265. 39 1169.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          59.17    PSIA     TOTAL PRESSURE          59.28   PSIA
STATIC PRESSURE         58.73    PSIA     STATIC PRESSURE         58.60   PSIA
VELOCITY DELTA P          .90     "HG     VELOCITY DELTA P         1.37    "HG
AIR TEMPERATURE          710.   DEG F     AIR TEMPERATURE          710.   DEG F
AIR VELOCITY           173.60  FT/SEC     AIR VELOCITY           214.64  FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.219    "HG

AIR FLOW DATA: P-REF= 104.1 PSIA   DELTA P= 2.80 "HG    T-REF=  96. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       309.      HZ     VOLUMETRIC FLOW RATE  13.48 GAL/HR
FUEL PRESSURE AT F/M   301.6     PSIA     FUEL TEMP AT F/M         97.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    54.33 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             57.73 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                9.84  "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    1.889 %     O2   19.200 %     CO     48.1 PPM     CHX       .6 PPM
 NO     28.1 PPM  NO2      4.4 PPM  NOX     32.5 PPM [NO(NDIR) + NO2(NDUV)]
 NO     17.3 PPM  NO2       .0 PPM  NOX     17.3 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    4.96                CHX=     .10
                  CHEMILUMINESCENCE NOX=  2.93,    NDIR + NDUV NOX=   5.51

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .008728
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8479 %
   CHECK ON F/A RATIO- F/A = .009072 W/O O2, CALCULATED O2 = 18.366 %

SMOKE INDEX:  29.58
SALTZMAN NOX =  35.8          PPM
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REMARKS:  Pressure Nozzle
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Figure 299. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG P/U 67, TEST SERIES 79, READING #     005
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-10-72                        READING WAS TAKEN AT 164119 HOURS

CYCLE POINT  5                                           40 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.448 LB/SEC    AVG BURNER INLET TEMP    715. DEG F
AVG BURNER INLET PRES   59.8   PSIA      AVG BURNER OUTLET TEMP 1327. DEG F
AVG BURNER DELTA P       9.89   "HG      PRESSURE LOSS            8.13 %
OVERALL F/A RATIO      .00942  (F/W)     FUEL FLOW RATE          82.98 LB/HR
AIR LOAD FACTOR         1.4031           PATTERN FACTOR         .34032
BOT HOT SPOT:  # 16 = 1535.  DEG F       MAX BOT / AVG BOT      1.1570
FUEL INLET TEMPERATURE 139.  DEG F       FUEL INLET PRESSURE      57.0  PSIA
HEAT LOADING PARAMETER  .24767E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1231.  6 1212. 15$$$$$$ 19 1368. 24 1439. 27 1320. 36 1430.
ANNULUS 2   4 1251.  7 1225. 16 1535. 21 1219. 25 1344. 34 1337. 37 1422.
ANNULUS 3   5 1162. 14 1433. 17 1487. 22 1231. 26 1260. 35 1308. 39 1163.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE           59.69   PSIA   TOTAL PRESSURE         59.88   PSIA
STATIC PRESSURE          59.15   PSIA   STATIC PRESSURE        59.36   PSIA
VELOCITY DELTA P          .:1    "HG    VELOCITY DELTA P        1.06    "HG
AIR TEMPERATURE          715.  DEG F    AIR TEMPERATURE         715.  DEG F
AIR VELOCITY            191.16 FT/SEC   AIR VELOCITY          188.45 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.393    "HG

AIR FLOW DATA: P-REF= 104.2 PSIA   DELTA P= 2.80 "HG   T-REF=  95. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       338.      HZ   VOLUMETRIC FLOW RATE  13.44 GAL/HR
FUEL PRESSURE AT F/M   303.9    PSIA    FUEL TEMP AT F/M         98.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    54.93 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             58.21 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                9.69  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    1.841 %     O2  19.100 %     CO      90.7 PPM     CHX      3.8 PPM
 NO     13.4 PPM  NO2      4.4 PPM  NOX     17.8 PPM (NO(NDIR) + NO2(NDUV))
 NO     12.8 PPM  NO2      2.8 PPM  NOX     15.6 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   9.40                  CHX=    .62
                 CHEMILUMINESCENCE NOX=  2.65,    NDIR + NDUV NOX=   3.03

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .008596
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6927 %
   CHECK ON F/A RATIO- F/A = .008868 W/O O2, CALCULATED O2 = 18.430 %

SMOKE INDEX:  1.45
SALTZMAN NOX =  18.4            PPM
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REMARKS:  Film Nozzle
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Figure 300. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection at Regenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG P/U 67, TEST SERIES 79, READING #    906
T63 FINAL PRECHAMBER MOD"B" 80% REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-1?-72                     READING WAS TAKEN AT 1726:28 HOURS

CYCLE POINT  4                                         55 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.534 LB/SEC     AVG BURNER INLET TEMP   764. DEG F
AVG BURNER INLET PRES  65.6    PSIA      AVG BURNER OUTLET TEMP 1452. DEG F
AVG BURNER DELTA P      10.70    "HG      PRESSURE LOSS            8.01 %
OVERALL F/A RATIO      .01358  (F/M)     FUEL FLOW RATE         100.35 LB/HR
AIR LOAD FACTOR        1.4138            PATTERN FACTOR          .41711
BOT HOT SPOT: # 16 = 1739.  DEG F        MAX BOT / AVG BOT      1.1976
FUEL INLET TEMPERATURE 153.  DEG F       FUEL INLET PRESSURE     63.2   PSIA
HEAT LOADING PARAMETER  .2720E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1344.  6 1382. 15 1659. 19 1456. 24 1576. 27 1492. 36 1565.
ANNULUS 2   4 1348.  7 1323. 16 1739. 21 1349. 25 1477. 34 1410. 37 1531.
ANNULUS 3   5 1281. 14 1577. 17 1673. 22 1364. 26 1373. 35 1397. 39 1269.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          65.57    PSIA    TOTAL PRESSURE          65.76   PSIA
STATIC PRESSURE         64.92    PSIA    STATIC PRESSURE         65.24   PSIA
VELOCITY DELTA P         1.37    "HG     VELOCITY DELTA P         1.02    "HG
AIR TEMPERATURE         764.    DEG F    AIR TEMPERATURE         764.   DEG F
AIR VELOCITY          209.46 FT/SEC      AIR VELOCITY          179.27 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.269    "HG

AIR FLOW DATA: P-REF= 143.5 PSIA   DELTA P= 3.26 "HG    T-REF=  92. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      472.      HZ     VOLUMETRIC FLOW RATE  16.26 GAL/HR
FUEL PRESSURE AT F/M  291.5     PSIA     FUEL TEMP AT F/M        99.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   60.38 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              64.10 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                10.57  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   2.056 %     O2  18.702 %     CO     22.5 PPM      CHX      1.0 PPM
 NO     31.6 PPM  NO2     5.6 PPM  NOX    37.3 PPM (NO(NDIR) + NO2(NDUV))
 NO     31.4 PPM  NO2     1.9 PPM  NOX    33.4 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   2.08                CHX=    .15
                   CHEMILUMINESCENCE NOX=   5.06,   NDIR + NDUV NOX=   5.65

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .009815
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8042 %
   CHECK ON F/A RATIO- F/A = .009873 W/O O2, CALCULATED O2 = 18.130 %

SMOKE INDEX: .64
SALTZMAN NOX = 45.6           PPM
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REMARKS: Film Nozzle
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Figure 301. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection at Regenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 67, TEST SERIES 79, READING #     907
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-10-72                        READING WAS TAKEN AT 1748: 8 HOURS

CYCLE POINT  4                                             55 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.618 LB/SEC    AVG BURNER INLET TEMP    764. DEG F
AVG BURNER INLET PRES  65.6    PSIA      AVG BURNER OUTLET TEMP 1451. DEG F
AVG BURNER DELTA P      10.69    "HG     PRESSURE LOSS             8.01 %
OVERALL F/A RATIO      .01064  (F/F)     FUEL FLOW RATE          100.31 LB/HR
AIR LOAD FACTOR        1.3961            PATTERN FACTOR          .30778
BOT HOT SPOT:  # 16 = 1663.  DEG F       MAX HOT / AVG BOT       1.1458
FUEL INLET TEMPERATURE 103.  DEG F       FUEL INLET PRESSURE      220.3  PSIA
HEAT LOADING PARAMETER  .27285E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1355.  6 1339. 15 1617. 19 1500. 24 1587. 27 1468. 36 1577.
ANNULUS 2   4 1371.  7 1327. 16 1663. 21 1319. 25 1483. 34 1455. 37 1579.
ANNULUS 3   5 1200. 14 1518. 17 1633. 22 1339. 25 1400. 35 1485. 39 1292.

LEFT SIDE                 *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE            65.48    PSIA    TOTAL PRESSURE            65.72   PSIA
STATIC PRESSURE           65.13    PSIA    STATIC PRESSURE           65.15   PSIA
VELOCITY DELTA P            .70     "HG    VELOCITY DELTA P           1.16    "HG
AIR TEMPERATURE           764.   DEG F     AIR TEMPERATURE            764.   DEG F
AIR VELOCITY             148.97 FT/SEC     AIR VELOCITY             191.48 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))             -.493    "HG

AIR FLOW DATA: P-REF= 103.7 PSIA    DELTA P= 3.20 "HG    T-REF=  90. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       372.      HZ      VOLUMETRIC FLOW RATE  16.26 GAL/HR
FUEL PRESSURE AT F/M   478.0     PSIA      FUEL TEMP AT F/M        100.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     60.35 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              63.67 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                10.45  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.107 %      O2   18.500 %      CO      34.4 PPM      CHX       .3 PPM
 NO     40.1 PPM   NO2      6.0 PPM   NOX      46.1 PPM (NO(NDIR) + NO2(NDUV))
 NO     39.2 PPM   NO2       .0 PPM   NOX      39.2 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   3.15                    CHX=     .04
                  CHEMILUMINESCENCE NOX=  5.91,   NDIR + NDUV NOX=     6.95

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:           .009898
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:   99.8983 %
   CHECK ON F/A RATIO- F/A = .010899 W/O O2, CALCULATED O2 = 18.063 %

SMOKE INDEX:  22.37
SALTZMAN NOX = 52.5                 PPM
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REMARKS: Pressure Nozzle
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Figure 302. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #    988
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-10-72                       READING WAS TAKEN AT 1814:27 HOURS

CYCLE POINT  3                                           75 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.814 LB/SEC    AVG BURNER INLET TEMP   840. DEG F
AVG BURNER INLET PRES   74.7   PSIA     AVG BURNER OUTLET TEMP 1597. DEG F
AVG BURNER DELTA P      11.03     G     PRESSURE LOSS             7.25 %
OVERALL F/A RATIO       .01201  (./P)   FUEL FLOW RATE          121.64 LB/HR
AIR LOAD FACTOR         1.3508          PATTERN FACTOR           .30844
BOT HOT SPOT:  # 16 = 1824.  DEG F      MAX BOT / AVG BOT        1.1423
FUEL INLET TEMPERATURE 104.  DEG F      FUEL INLET PRESSURE      264.9  PSIA
HEAT LOADING PARAMETER  .29064E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1517.  6 1437. 15 1753. 19 1675. 24 1782. 27 1626. 36 1781.
ANNULUS 2   4 1563.  7 1463. 16 1824. 21 1407. 25 1625. 34 1579. 37 1745.
ANNULUS 3   5 1402. 14 1633. 17 1797. 22 1403. 26 1531. 35 1511. 39 1415.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          74.78   PSIA    TOTAL PRESSURE          74.66  PSIA
STATIC PRESSURE         74.17   PSIA    STATIC PRESSURE         73.94  PSIA
VELOCITY DELTA P         1.06    "HG    VELOCITY DELTA P         1.46   "HG
AIR TEMPERATURE         841.   DEG F    AIR TEMPERATURE         840.  DEG F
AIR VELOCITY           177.34 FT/SEC    AIR VELOCITY           208.18 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          .076   "HG

AIR FLOW DATA: P-REF= 103.2 PSIA   DELTA P= 3.71 "HG    T-REF=  80. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       451.      HZ   VOLUMETRIC FLOW RATE  19.74 GAL/HR
FUEL PRESSURE AT F/M   912.1     PSIA   FUEL TEMP AT F/M         102.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   69.26 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            72.98 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE              11.06  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2   2.352 %     O2  18.200 %     CO     32.8 PPM     CHX       .1 PPM
 NO    63.7 PPM  NO2     8.1 PPM  NOX     71.8 PPM (NO(NDIR) + NO2(NDUV))
 NO    68.7 PPM  NO2      .0 PPM  NOX     68.7 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   2.67                 CHX=    .01
              CHEMILUMINESCENCE NOX=    9.19,    NDIR + NDUV NOX=   9.61

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011000
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8082 %
  CHECK ON F/A RATIO- F/A = .011257 W/O O2, CALCULATED O2 = 17.720 %

SMOKE INDEX: 22.99
SALTZMAN NOX = 763               PPM
**********************************************************************
REMARKS: Pressure Nozzle
```

Figure 303. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 55% Power.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING # 989
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE: 8-1?-72 READING WAS TAKEN AT 1833:37 HOURS

CYCLE POINT 3 75 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.805 LB/SEC		AVG BURNER INLET TEMP	841.	DEG F
AVG BURNER INLET PRES	75.0	PSIA	AVG BURNER OUTLET TEMP	1687.	DEG F
AVG BURNER DELTA P	11.62	"HG	PRESSURE LOSS	7.61	%
OVERALL F/A RATIO	.01209	(F/P)	FUEL FLOW RATE	122.06	LB/HR
AIR LOAD FACTOR	1.3489		PATTERN FACTOR	.33355	
BOT HOT SPOT: # 16 = 1863.	DEG F		MAX BOT / AVG BOT	1.1598	
FUEL INLET TEMPERATURE 295.	DEG F		FUEL INLET PRESSURE	71.4	PSIA

HEAT LOADING PARAMETER .29041E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1585.	6	1456.	15	1770.	19	1618.	24	1752.	27	1608.	36	1718.
ANNULUS 2	4	1497.	7	1480.	16	1863.	21	1592.	25	1633.	34	1585.	37	1727.
ANNULUS 3	5	1420.	14	1751.	17	1792.	22	1545.	26	1520.	35	1564.	39	1434.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE			RIGHT SIDE		
TOTAL PRESSURE	74.92	PSIA	TOTAL PRESSURE	75.07	PSIA
STATIC PRESSURE	74.23	PSIA	STATIC PRESSURE	74.27	PSIA
VELOCITY DELTA P	1.41	"HG	VELOCITY DELTA P	1.64	"HG
AIR TEMPERATURE	841.	DEG F	AIR TEMPERATURE	841.	DEG F
AIR VELOCITY	204.13	FT/SEC	AIR VELOCITY	219.84	FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.314 "HG

AIR FLOW DATA: P-REF= 103.2 PSIA DELTA P= 3.68 "HG T-REF= 87. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	453.	HZ	VOLUMETRIC FLOW RATE	19.83	GAL/HR
FUEL PRESSURE AT F/M	419.0	PSIA	FUEL TEMP AT F/M	103.	DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 69.20 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 73.20 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 11.40 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2	2.283 %	O2	18.258 %	CO	30.0 PPM	CHX	.4 PPM
NO	62.3 PPM	NO2	7.2 PPM	NOX	69.5 PPM	(NO(NDIR) + NO2(NDUV))	
NO	70.7 PPM	NO2	.0 PPM	NOX	70.7 PPM	(CHEMILUMINESCENCE)	

EMISSIONS INDEX, LB/1000 LB FUEL: CO= 2.92 CHX= .05
CHEMILUMINESCENCE NOX= 9.40, NDIR + NDUV NOX= 9.24

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .010714
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.8730 %
CHECK ON F/A RATIO= F/A = .016933 W/O O2, CALCULATED O2 = 17.816 %

SMOKE INDEX: .52
SALTZMAN NOX = 79.0 PPM

REMARKS: Film Nozzle

Figure 304. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection at Regenerative 75% Power.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #    910
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-10-72                          READING WAS TAKEN AT 1059:45 HOURS

CYCLE POINT  2                                               100 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW        3.064 LB/SEC     AVG BURNER INLET TEMP    970. DEG F
AVG BURNER INLET PRES  84.8    PSIA     AVG BURNER OUTLET TEMP 1040. DEG F
AVG BURNER DELTA P     14.37    "HG     PRESSURE LOSS             8.32 %
OVERALL F/A RATIO     .01409  (F/M)     FUEL FLOW RATE          155.40 LB/HR
AIR LOAD FACTOR        1.3663           PATTERN FACTOR          .32593
BOT HOT SPOT:  # 16 = 2134.  DEG F      MAX BOT / AVG BOT       1.1548
FUEL INLET TEMPERATURE 100.  DEG F      FUEL INLET PRESSURE       71.4  PSIA
HEAT LOADING PARAMETER  .32699E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1603.  6 1684. 15 2072. 19 1702. 24 2012. 27 1675. 36 2049.
ANNULUS 2    4 1654.  7 1721. 16 2134. 21 1701. 25 1919. 34 1797. 37 1900.
ANNULUS 3    5 1633. 14 2067. 17 2073. 22 1752. 26 1702. 35 1797. 39 1035.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE            84.72    PSIA    TOTAL PRESSURE            84.09   PSIA
STATIC PRESSURE           84.13    PSIA    STATIC PRESSURE           84.15   PSIA
VELOCITY DELTA P          1.21      "HG    VELOCITY DELTA P          1.50     "HG
AIR TEMPERATURE           971.   DEG F     AIR TEMPERATURE           970.   DEG F
AIR VELOCITY             186.07 FT/SEC     AIR VELOCITY             207.31 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))              -.348    "HG

AIR FLOW DATA: P-REF= 102.0 PSIA   DELTA P= 4.40 "HG   T-REF= 85. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      578.     HZ    VOLUMETRIC FLOW RATE  25.20 GAL/HR
FUEL PRESSURE AT F/M  359.0    PSIA    FUEL TEMP AT F/M        100.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   77.78 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            82.24 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE              14.10  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    2.675 %     O2  17.300 %      CO     31.2 PPM      CHX       .0 PPM
 NO    122.6 PPM  NO2      0.1 PPM  NOX    130.7 PPM (NO(NDIR) + NO2(NDUV))
 NO    133.0 PPM  NO2       .0 PPM  NOX    133.0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   2.17                    CHX=    .10
                  CHEMILUMINESCENCE NOX=  10.21,   NDIR + NDUV NOX=  14.94

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .012702
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8660 %
   CHECK ON F/A RATIO- F/A = .012702 W/O O2, CALCULATED O2 = 17.267 %

SMOKE INDEX:    1.13
SALTZMAN NOX = X                         PPM
-----------------------------------------------------------------------------
REMARKS:   Film Nozzle
```

Figure 305. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection at Regenerative 100% Power.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 79, READING #    911
T63 FINAL PRECHAMBER MOD"B" RUN REGENERATIVE T63 INLET CONDITIONS
TEST DATE:  8-18-72                         READING WAS TAKEN AT 1918123 HOURS

CYCLE POINT  2                                          100 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          3.039 LB/SEC     AVG BURNER INLET TEMP   978. DEG F
AVG BURNER INLET PRES  84.7    PSIA      AVG BURNER OUTLET TEMP 1851. DEG F
AVG BURNER DELTA P     14.06    "HG      PRESSURE LOSS              6.15 %
OVERALL F/A RATIO      .01419  (F/M)     FUEL FLOW RATE          155.26 LB/HR
AIR LOAD FACTOR        1.3562            PATTERN FACTOR           .31190
BOT HOT SPOT: # 16 = 2126.   DEG F       MAX BOT / AVG BOT       1.1405
FUEL INLET TEMPERATURE 102.  DEG F       FUEL INLET PRESSURE      324.1   PSIA
HEAT LOADING PARAMETER   .32693E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1716.  6 1663. 15 2074. 19 1821. 24 2016. 27 1888. 38 2042.
ANNULUS 2   4 1759.  7 1684. 16 2126. 21 1659. 25 1921. 34 1883. 37 1992.
ANNULUS 3   5 1628. 14 2020. 17 2066. 22 1603. 26 1798. 35 1932. 39 1686.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          84.61    PSIA    TOTAL PRESSURE          84.87   PSIA
STATIC PRESSURE         84.12    PSIA    STATIC PRESSURE         84.18   PSIA
VELOCITY DELTA P         1.01     "HG    VELOCITY DELTA P         1.30    "HG
AIR TEMPERATURE          979.   DEG F    AIR TEMPERATURE          978.  DEG F
AIR VELOCITY           170.29 FT/SEC     AIR VELOCITY           190.33 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))      -.522    "HG

AIR FLOW DATA: P-REF= 102.6 PSIA   DELTA P= 4.31 "HG   T-REF= 82. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        577.      HZ    VOLUMETRIC FLOW RATE  28.24 GAL/HR
FUEL PRESSURE AT F/M   557.4    PSIA     FUEL TEMP AT F/M         104.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    77.83 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             82.02 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               13.80  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.700 %     O2  17.250 %      CO     20.2 PPM      CHX      .0 PPM
 NO    122.6 PPM  NO2      8.5 PPM  NOX    131.1 PPM (NO(NDIR) + NO2(NDUV))
 NO    130.0 PPM  NO2       .0 PPM  NOX    130.0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    2.02                  CHX=    .00
                  CHEMILUMINESCENCE NOX=  15.41,    NDIR + NDUV NOX=  14.80

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:      .012000
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8872 %
   CHECK ON F/A RATIO- F/A = .012000 W/O O2, CALCULATED O2 = 17.233 %

SMOKE INDEX:  26.6
SALTZMAN NOX = x                        PPM
*************************************************************************
REMARKS:  Pressure Nozzle
```

Figure 306. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection at Regenerative 100% Power.

TABLE LXXVIII. EMISSION INDEX SUMMARY FOR T63-A-5A GAS TURBINE ENGINE COMBUSTORS RIG TESTED AT REGENERATIVE ENGINE CONDITIONS OVER THE LOW DUTY CYCLE

Combustor	Emission Constituent: C_xH_y	CO	NO_x	Particulates	Total Emissions
EMISSION INDEX (lb emissions/1000 lb fuel)					
Baseline T63-A-5A					
• Nonregenerative	.378	13.804	8.412	.040	22.634
• Regenerative	.118	9.488	9.403	.346	19.355
Final Design Prechamber Mod. "B"					
• Wall Fuel Film	2.239	6.873	6.536	.012	15.660
• Pressure Atomizer	.073	4.321	7.735	.455	12.584

TABLE LXXIX. EMISSION INDEX SUMMARY FOR T63-A-5A GAS TURBINE ENGINE COMBUSTORS RIG TESTED AT REGENERATIVE ENGINE CONDITIONS OVER THE LOH DUTY CYCLE

	Emission Constituent				
Combustor	C_xH_y	CO	NO_x	Particulates	Total Emissions
RELATIVE EMISSION INDEX (%)					
Baseline T63-A-5A					
• Nonregenerative	100	100	100	100	100
• Regenerative	31	69	112	865	86
Final Design Prechamber Mod. "B"					
• Wall Fuel Film	592	50	78	30	69
• Pressure Atomizer	19	31	92	1138	56

Airflow Rate, W_a	=	0.20 lb/sec
Inlet Temperature, BIT	=	84°F
Inlet Pressure, BIP	=	14.5 psia
Fuel-Air Ratio, F/A	=	0.047
Fuel Flow Rate, W_f	=	34 lb/hr

These conditions were maintained for 60 seconds with the spark igniter activated. A light-off was not obtained in either fuel injection mode. Data acquisition readings taken prior to and during each fire-up attempt are presented in Figures 307 through 310. Repositioning the spark igniter in the dome adjacent to the atomizer nozzle during startup with the pressure atomizer fuel injection should have produced satisfactory results. Similarly, repositioning the spark igniter flush with the vaporizer tube wall and slightly downstream from the wall film injector holes may have produced ignition in the wall fuel film injection mode.

Emission /combustor data were obtained for the Final Prechamber Modification "B" combustor liner operating on both fuel injection modes for a nine-point set of parametric combustor conditions. Three values of four parameters were set on the combustor, the middle value of the three being the nominal test value. The parametric point values tested were the following:

Airflow Rate, W_a (lb/sec)	1	2	3
Inlet Temperature, BIT (°F)	200	600	1000
Inlet Pressure, BIP (psia)	32	60	92
Exhaust Temperature, BOT (°F)	1100	1500	1700

The nine parametric operating conditions at which the Prechamber Modification "B" combustor was tested using wall fuel film injection are reproduced in Figures 311 through 319. A summary of these data is seen in Table LXXX. The detailed test results for pressure atomizer operation are given in Figures 320 through 328 and summarized in Table LXXX.

Modification "C"

Final Prechamber Modification "C" was a simple change to Modification "B", viz, that of closing the twelve reaction-zone air admission holes. It was intended that wall fuel vaporization would be

T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 8R, READING # 912
T63 FINAL PRECHAMBER, MOD "B" RUN ELECTRICAL IGNITION STUDY ON VEE PLUG
TEST DATE: 8-11-72 READING WAS TAKEN AT 1421:42 HOURS

CYCLE POINT 7 0 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	.204 LB/SEC	AVG BURNER INLET TEMP	84. DEG F
AVG BURNER INLET PRES	14.5 PSIA	AVG BURNER OUTLET TEMP	83. DEG F
AVG BURNER DELTA P	.13 "HG	PRESSURE LOSS	.45 %
OVERALL F/A RATIO	.00000 (F/M)	FUEL FLOW RATE	.00 LB/HR
AIR LOAD FACTOR	.3293	PATTERN FACTOR	-.44293
BOT HOT SPOT: # 34 =	83. DEG F	MAX BOT / AVG BOT	1.0049
FUEL INLET TEMPERATURE	83. DEG F	FUEL INLET PRESSURE	14.2 PSIA
HEAT LOADING PARAMETER	.00000E+00 BTU/HOUR/ATM/CUBIC FOOT		

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	83.	6	83.	15	83.	19	83.	24	83.	27	83.	36	83.
ANNULUS 2	4	83.	7	83.	16	83.	21	83.	25	83.	34	83.	37	83.
ANNULUS 3	5	82.	14	83.	17	82.	22	83.	26	82.	35	83.	39	83.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	14.46 PSIA	TOTAL PRESSURE	14.46 PSIA
STATIC PRESSURE	14.45 PSIA	STATIC PRESSURE	14.45 PSIA
VELOCITY DELTA P	.02 "HG	VELOCITY DELTA P	.02 "HG
AIR TEMPERATURE	84. DEG F	AIR TEMPERATURE	84. DEG F
AIR VELOCITY	33.40 FT/SEC	AIR VELOCITY	31.89 FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.003 "HG

AIR FLOW DATA: P-REF= 109.6 PSIA DELTA P= .24 "HG T-REF= 92. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	. HZ	VOLUMETRIC FLOW RATE	.00 GAL/HR
FUEL PRESSURE AT F/M	13.8 PSIA	FUEL TEMP AT F/M	83. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 14.39 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 14.52 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE .13 "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX = X PPM

REMARKS:

Pre fire data

Figure 307. Final Prechamber Liner Modification "B" Startup Test on Wall Fuel Film Injection - Prefire Conditions.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 80, READING #    913
T63 FINAL PRECHAMBER, MOD "B"  RUN ELECTRICAL IGNITION STUDY ON VEE PLUG
TEST DATE:  8-11-72                      READING WAS TAKEN AT 1425:35 HOURS

CYCLE POINT  7                                            0 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          .209 LB/SEC     AVG BURNER INLET TEMP      85. DEG F
AVG BURNER INLET PRES  14.7    PSIA      AVG BURNER OUTLET TEMP     75. DEG F
AVG BURNER DELTA P        .16    "HG     PRESSURE LOSS               .55 %
OVERALL F/A RATIO     .04718   (F/F)     FUEL FLOW RATE            35.53 LB/HR
AIR LOAD FACTOR          .3325           PATTERN FACTOR           -.55784
BOT HOT SPOT:  # 27 =     80.   DEG F    MAX BOT / AVG BOT         1.0691
FUEL INLET TEMPERATURE   83.   DEG F     FUEL INLET PRESSURE        14.5  PSIA
HEAT LOADING PARAMETER   .43203E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2   77.  6   76.  15  73.  19  68.  24  72.  27  80.  36  75.
ANNULUS 2    4   76.  7   78.  16  73.  21  69.  25  76.  34  78.  37  75.
ANNULUS 3    5   78.  14  76.  17  74.  22  71.  26  80.  35  77.  39  77.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          14.67    PSIA    TOTAL PRESSURE          14.68   PSIA
STATIC PRESSURE         14.66    PSIA    STATIC PRESSURE         14.67   PSIA
VELOCITY DELTA P          .03    "HG     VELOCITY DELTA P          .01   "HG
AIR TEMPERATURE          85.   DEG F     AIR TEMPERATURE          84.  DEG F
AIR VELOCITY            40.04 FT/SEC     AIR VELOCITY            38.25 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.002    "HG

AIR FLOW DATA: P-REF= 110.0 PSIA    DELTA P=  .25 "HG    T-REF=  92. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      130.      HZ     VOLUMETRIC FLOW RATE    5.71 GAL/HR
FUEL PRESSURE AT F/M    94.2    PSIA     FUEL TEMP AT F/M         83.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     14.59 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              14.53 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  .16  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX = X                   PPM
---------------------------------------------------------------------------
REMARKS:
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Data During Flu Attempt
Film Nozzle

Figure 308. Final Prechamber Liner Modification "B" Startup Test on Wall Fuel Film Injection - Conditions During Fireup Attempt.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 80, READING #    914
T63 FINAL PRECHAMBER, MOD "B"  RUN ELECTRICAL IGNITION STUDY ON VEE PLUG
TEST DATE: 8-11-72                        READING WAS TAKEN AT 1431:54 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          .172 LB/SEC     AVG BURNER INLET TEMP     85. DEG F
AVG BURNER INLET PRES  14.5    PSIA      AVG BURNER OUTLET TEMP    83. DEG F
AVG BURNER DELTA P       .12    "HG      PRESSURE LOSS                .42 %
OVERALL F/A RATIO     .00000  (F/M)      FUEL FLOW RATE              .00 LB/HR
AIR LOAD FACTOR        .2775             PATTERN FACTOR          -.49818
BOT HOT SPOT: # 34 =    84.   DEG F      MAX BOT / AVG BOT       1.0087
FUEL INLET TEMPERATURE  83.   DEG F      FUEL INLET PRESSURE       14.2  PSIA
HEAT LOADING PARAMETER  .00000E+00 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2   84.  6   84. 15   84. 19   84. 24   84. 27   84. 36   84.
ANNULUS 2    4   84.  7   83. 16   83. 21   83. 25   83. 34   84. 37   84.
ANNULUS 3    5   83. 14   83. 17   83. 22   83. 26   83. 35   83. 39   83.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          14.46    PSIA    TOTAL PRESSURE         14.46   PSIA
STATIC PRESSURE         14.45    PSIA    STATIC PRESSURE        14.45   PSIA
VELOCITY DELTA P          .02     "HG    VELOCITY DELTA P         .01    "HG
AIR TEMPERATURE           85.   DEG F    AIR TEMPERATURE          85.  DEG F
AIR VELOCITY            34.27 FT/SEC     AIR VELOCITY           29.32 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]        -.002    "HG

AIR FLOW DATA: P-REF= 109.8 PSIA   DELTA P=  .17 "HG    T-REF=  92. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY           .       HZ    VOLUMETRIC FLOW RATE     .00 GAL/HR
FUEL PRESSURE AT F/M     13.9    PSIA    FUEL TEMP AT F/M          83.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    14.40 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             14.51 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 .12  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX =X                      PPM
--------------------------------------------------------------------------
REMARKS:
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Prefire Data

Figure 309. Final Prechamber Liner Modification "B" Startup Test on Wall Fuel Film Injection - Prefire Conditions.

```
T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 80, READING #    915
T63 FINAL PRECHAMBER, MOD "B"  RUN ELECTRICAL IGNITION STUDY ON VEE PLUG
TEST DATE:  8-11-72                    READING WAS TAKEN AT 1434:25 HOURS

CYCLE POINT  7                                        0 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          .190 LB/SEC    AVG BURNER INLET TEMP     85. DEG F
AVG BURNER INLET PRES  14.7    PSIA     AVG BURNER OUTLET TEMP    76. DEG F
AVG BURNER DELTA P        .13   "HG     PRESSURE LOSS              .44 %
OVERALL F/A RATIO      .04769  (F/M)    FUEL FLOW RATE           32.63 LB/HR
AIR LOAD FACTOR          .3018          PATTERN FACTOR          -.54147
BOT HOT SPOT:  # 27 =    81.  DEG F     MAX BOT / AVG BOT       1.0663
FUEL INLET TEMPERATURE  83.  DEG F     FUEL INLET PRESSURE     102.3   PSIA
HEAT LOADING PARAMETER  .39599E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2   77.  6   77. 15   73. 19   70. 24   74. 27   81. 36   76.
ANNULUS 2  4   77.  7   78. 16   74. 21   70. 25   76. 34   78. 37   76.
ANNULUS 3  5   79. 14   76. 17   74. 22   72. 26   80. 35   79. 39   78.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE         14.70    PSIA    TOTAL PRESSURE          14.71    PSIA
STATIC PRESSURE        14.69    PSIA    STATIC PRESSURE         14.70    PSIA
VELOCITY DELTA P         .02     "HG    VELOCITY DELTA P          .02     "HG
AIR TEMPERATURE          85.  DEG F     AIR TEMPERATURE           85.  DEG F
AIR VELOCITY           37.88 FT/SEC     AIR VELOCITY            31.37 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.004     "HG

AIR FLOW DATA: P-REF= 110.1 PSIA   DELTA P=  .21 "HG    T-REF=  92. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      119.      HZ    VOLUMETRIC FLOW RATE    5.24 GAL/HR
FUEL PRESSURE AT F/M  143.3    PSIA     FUEL TEMP AT F/M          84.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    14.64 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             14.53 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 .13  "HG (XDUCER # 13)

SMOKE INDEX:X
SALTZMAN NOX =X                     PPM
-------------------------------------------------------------------------
REMARKS:
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Data During F/u Attempt
Pressure Nozzle

Figure 310. Final Prechamber Liner Modification "B" Startup Test on Pressure Atomizer Injection - Conditions During Fireup Attempt.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 07, TEST SERIES 81, READING #    916
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE: 8-11-72                         READING WAS TAKEN AT 1605:43 HOURS

CYCLE POINT  7                                            0 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW        2.035 LB/SEC    AVG BURNER INLET TEMP    399. DEG F
AVG BURNER INLET PRES  59.4    PSIA    AVG BURNER OUTLET TEMP 1482. DEG F
AVG BURNER DELTA P      5.11    "HG    PRESSURE LOSS              4.23 %
OVERALL F/A RATIO      .01583  (F/M)   FUEL FLOW RATE           116.01 LB/HR
AIR LOAD FACTOR        1.0038          PATTERN FACTOR           .56056
BOT HOT SPOT: # 16 = 2096.  DEG F     *MAX BOT / AVG BOT        1.4142
FUEL INLET TEMPERATURE  89.  DEG F     FUEL INLET PRESSURE        56.8  PSIA
HEAT LOADING PARAMETER  .34852E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1216.  6 1123. 15 1921. 19 1672. 24 1577. 27 1416. 36 1682.
ANNULUS 2   4 1286.  7 1167. 16 2096. 21 1158. 25 1427. 34 1573. 37 1787.
ANNULUS 3   5 1040. 14 1859. 17 1966. 22 1176. 26 1312. 35 1517. 39 1154.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***         RIGHT SIDE
TOTAL PRESSURE           59.38    PSIA   TOTAL PRESSURE          59.41   PSIA
STATIC PRESSURE          59.17    PSIA   STATIC PRESSURE         59.06   PSIA
VELOCITY DELTA P           .42     "HG   VELOCITY DELTA P          .72    "HG
AIR TEMPERATURE           399.  DEG F    AIR TEMPERATURE          399.  DEG F
AIR VELOCITY            101.92 FT/SEC    AIR VELOCITY           133.04 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.070    "HG

AIR FLOW DATA: P-REF= 134.2 PSIA   DELTA P=27.79 "HG   T-REF=  95. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       427.      HZ    VOLUMETRIC FLOW RATE  18.60 GAL/HR
FUEL PRESSURE AT F/M   123.6     PSIA    FUEL TEMP AT F/M           89.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    56.88 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             58.61 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.08  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   3.158 %     O2  17.300 %     CO   290.7 PPM      CHX    10.8 PPM
 NO     24.6 PPM  NO2     13.3 PPM  NOX    37.9 PPM (NO(NDIR) + NO2(NDUV))
 NO 28.6 PPM  NO2 12.6 PPM  NOX 41.1 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12.48                  CHX=   1.05
               CHEMILUMINESCENCE NOX=  4.19,    NDIR + NDUV NOX=   3.86

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .014652
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8800 %
   CHECK ON F/A RATIO- F/A = .015143 W/O O2, CALCULATED O2 = 16.506 %

SMOKE INDEX: 7.17
SALTZMAN NOX = 44.0                 PPM
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REMARKS: Input Error on CL NO/NO2
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Figure 311. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at BIT = 400°F.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 81, READING #    917
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE: 8-11-72                       READING WAS TAKEN AT 1641: 0 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.029 LB/SEC    AVG BURNER INLET TEMP   600. DEG F
AVG BURNER INLET PRES  60.4    PSIA     AVG BURNER OUTLET TEMP 1502. DEG F
AVG BURNER DELTA P      6.73    "HG     PRESSURE LOSS             5.47 %
OVERALL F/A RATIO      .01387  (F/M)    FUEL FLOW RATE          101.34 LB/HR
AIR LOAD FACTOR        1.0929           PATTERN FACTOR          .26978
BOT HOT SPOT: # 16 = 1745.  DEG F       MAX BOT / AVG BOT       1.1628
FUEL INLET TEMPERATURE  92.  DEG F      FUEL INLET PRESSURE       56.4  PSIA
HEAT LOADING PARAMETER  .29922E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1444.  6 1323. 15 1715. 19 1442. 24 1682. 27 1589. 36 1545.
ANNULUS 2   4 1441.  7 1341. 16 1745. 21 1413. 25 1613. 34 1455. 37 1548.
ANNULUS 3   5 1280. 14 1732. 17 1629. 22 1471. 26 1428. 35 1484. 39 1296.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          60.40   PSIA    TOTAL PRESSURE          60.46   PSIA
STATIC PRESSURE         60.16   PSIA    STATIC PRESSURE         60.17   PSIA
VELOCITY DELTA P          .49    "HG    VELOCITY DELTA P          .60    "HG
AIR TEMPERATURE          600.  DEG F    AIR TEMPERATURE          600.  DEG F
AIR VELOCITY          121.12 FT/SEC     AIR VELOCITY          132.97 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.114   "HG

AIR FLOW DATA: P-REF= 104.4 PSIA   DELTA P=27.55 "HG   T-REF=  95. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       374.      HZ   VOLUMETRIC FLOW RATE  16.38 GAL/HR
FUEL PRESSURE AT F/M   128.4    PSIA    FUEL TEMP AT F/M            92.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   57.13 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            59.60 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               6.67  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2   2.525 %    O2  18.200 %     CO     91.9 PPM     CHX      2.7 PPM
 NO    39.4 PPM  NO2    11.5 PPM  NOX    50.8 PPM (NO(NDIR) + NO2(NDUV))
 NO    39.2 PPM  NO2     4.9 PPM  NOX    44.1 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   6.49                 CHX=    .30
                 CHEMILUMINESCENCE NOX=  5.11,   NDIR + NDUV NOX=    5.90

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011700
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7713 %
   CHECK ON F/A RATIO- F/A = .012107 W/O O2. CALCULATED O2 = 17.476 %

SMOKE INDEX: 2.87
SALTZMAN NOX = 55.7                   PPM
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Figure 312. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection at Parametric Test Nominal Conditions.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 81, READING # 918

T63 FINAL PRECHAMBER, MOD "B" RUNNING PARAMETRIC PERFORMANCE STUDIES.

TEST DATE: 8-11-72 READING WAS TAKEN AT 172913 HOURS

CYCLE POINT 7 0 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.055 LB/SEC	AVG BURNER INLET TEMP	1002. DEG F
AVG BURNER INLET PRES	60.0 PSIA	AVG BURNER OUTLET TEMP	1499. DEG F
AVG BURNER DELTA P	9.18 "HG	PRESSURE LOSS	7.51 %
OVERALL F/A RATIO	.00848 (F/M)	FUEL FLOW RATE	62.74 LB/HR
AIR LOAD FACTOR	1.3000	PATTERN FACTOR	.21322
BOT HOT SPOT: # 15 = 1625. DEG F		MAX BOT / AVG BOT	1.0841
FUEL INLET TEMPERATURE	96. DEG F	FUEL INLET PRESSURE	54.2 PSIA

HEAT LOADING PARAMETER .18643E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1457.	6	1445.	15	1625.	19	1456.	24	1591.	27	1478.	36	1614.
ANNULUS 2	4	1475.	7	1466.	16	1624.	21	1448.	25	1518.	34	1470.	37	1557.
ANNULUS 3	5	1389.	14	1600.	17	1543.	22	1455.	26	1425.	35	1430.	39	1421.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	60.00 PSIA	TOTAL PRESSURE	60.10 PSIA
STATIC PRESSURE	59.60 PSIA	STATIC PRESSURE	59.60 PSIA
VELOCITY DELTA P	.81 "HG	VELOCITY DELTA P	.85 "HG
AIR TEMPERATURE	1002. DEG F	AIR TEMPERATURE	1002. DEG F
AIR VELOCITY	183.29 FT/SEC	AIR VELOCITY	187.54 FT/SEC

DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.215 "HG

AIR FLOW DATA: P-REF= 104.7 PSIA DELTA P=27.94 "HG T-REF= 90. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	233. HZ	VOLUMETRIC FLOW RATE	10.14 GAL/HR
FUEL PRESSURE AT F/M	141.1 PSIA	FUEL TEMP AT F/M	98. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE	55.54 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE	58.74 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE	9.07 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *

GAS SAMPLES TAKEN IN PLANE #1

CO2	1.769 %	O2	19.200 %	CO	22.1 PPM	CHX	1.0 PPM
NO	22.5 PPM	NO2	2.4 PPM	NOX	24.9 PPM	[NO(NDIR) + NO2(NDUV)]	
NO	20.1 PPM	NO2	.0 PPM	NOX	18.1 PPM	[CHEMILUMINESCENCE]	

EMISSIONS INDEX, LB/1000 LB FUEL: CO= 2.54 CHX= .18

CHEMILUMINESCENCE NOX= 3.41, NDIR + NDUV NOX= 4.71

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .008231

CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.9839 %

CHECK ON F/A RATIO- F/A = .008489 W/O O2, CALCULATED O2 = 18.836 %

SMOKE INDEX: X

SALTZMAN NOX = 26.4 PPM

Figure 313. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test BIT = 1000°F.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 81, READING #    919
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE: 8-11-72                        READING WAS TAKEN AT 1800:40 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.031 LB/SEC    AVG BURNER INLET TEMP    597. DEG F
AVG BURNER INLET PRES  32.5    PSIA      AVG BURNER OUTLET TEMP 1503. DEG F
AVG BURNER DELTA P     14.21    "HG      PRESSURE LOSS            21.48 %
OVERALL F/A RATIO     .01425  (F/P)      FUEL FLOW RATE         104.17 LB/HR
AIR LOAD FACTOR        2.0311            PATTERN FACTOR          .29729
BOT HOT SPOT:  # 16 = 1772.  DEG F       MAX BOT / AVG BOT       1.1791
FUEL INLET TEMPERATURE  95.  DEG F       FUEL INLET PRESSURE      27.7  PSIA
HEAT LOADING PARAMETER  .57185E+07 BTU/HOUR/ATM/CUBIC FOOT

               **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1437.  6 1270. 15 1693. 19 1387. 24 1709. 27 1568. 36 1534.
ANNULUS 2   4 1422.  7 1294. 16 1772. 21 1337. 25 1655. 34 1469. 37 1575.
ANNULUS 3   5 1290. 14 1767. 17 1636. 22 1448. 26 1517. 35 1476. 39 1308.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          32.41    PSIA    TOTAL PRESSURE         32.68   PSIA
STATIC PRESSURE         31.72    PSIA    STATIC PRESSURE        32.07   PSIA
VELOCITY DELTA P         1.41    "HG     VELOCITY DELTA P        1.08    "HG
AIR TEMPERATURE         598.  DEG F      AIR TEMPERATURE         597.  DEG F
AIR VELOCITY          261.23 FT/SEC      AIR VELOCITY          244.87 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.395    "HG

AIR FLOW DATA: P-REF= 104.6 PSIA   DELTA P=27.13 "HG   T-REF=  87. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      385.      HZ     VOLUMETRIC FLOW RATE  16.84 GAL/HR
FUEL PRESSURE AT F/M  135.8    PSIA      FUEL TEMP AT F/M         95.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE       25.52 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                30.01 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  14.01  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.058 %     O2  18.509 %     CO    651.8 PPM     CHX     81.0 PPM
 NO      9.8 PPM  NO2      8.1 PPM  NOX    17.9 PPM (NO(NDIR) + NO2(NDUV))
 NO      9.5 PPM  NO2     10.1 PPM  NOX    19.6 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  44.84                 CHX=    5.53
                   CHEMILUMINESCENCE NOX=  2.21,    NDIR + NDUV NOX=   2.02

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010634
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  97.7830 %
   CHECK ON F/A RATIO- F/A = .010234 W/O O2. CALCULATED O2 = 18.079 %

SMOKE INDEX: X
SALTZMAN NOX = 18.7                  PPM
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Figure 314. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at BIP = 32 psia.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 81, READING #    920
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE:  8-11-72                     READING WAS TAKEN AT 1836155 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.035 LB/SEC    AVG BURNER INLET TEMP   601. DEG F
AVG BURNER INLET PRES  92.7    PSIA      AVG BURNER OUTLET TEMP 1510. DEG F
AVG BURNER DELTA P      3.76    "HG      PRESSURE LOSS             1.99 %
OVERALL F/A RATIO      .01359  (F/M)     FUEL FLOW RATE           99.57 LB/HR
AIR LOAD FACTOR        .7152             PATTERN FACTOR          .30246
BOT HOT SPOT:  # 16 = 1857.  DEG F       MAX BOT / AVG BOT       1.2302
FUEL INLET TEMPERATURE  93.  DEG F       FUEL INLET PRESSURE      87.4  PSIA
HEAT LOADING PARAMETER  .19170E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1345.  6 1260. 15 1822. 19 1485. 24 1760. 27 1697. 36 1521.
ANNULUS 2   4 1323.  7 1317. 16 1857. 21 1488. 25 1677. 34 1392. 37 1524.
ANNULUS 3   5 1187. 14 1717. 17 1730. 22 1553. 26 1410. 35 1370. 39 1289.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           92.69    PSIA   TOTAL PRESSURE           92.68   PSIA
STATIC PRESSURE          92.44    PSIA   STATIC PRESSURE          92.55   PSIA
VELOCITY DELTA P           .50    "HG    VELOCITY DELTA P           .26   "HG
AIR TEMPERATURE           601.  DEG F    AIR TEMPERATURE           601.  DEG F
AIR VELOCITY             98.73 FT/SEC    AIR VELOCITY             71.50 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           .023    "HG

AIR FLOW DATA: P-REF= 105.2 PSIA   DELTA P=26.39 "HG   T-REF=  74. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       368.     HZ     VOLUMETRIC FLOW RATE  16.09 GAL/HR
FUEL PRESSURE AT F/M   135.6    PSIA     FUEL TEMP AT F/M         94.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   90.83 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            92.87 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               3.76  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   2.700 %     O2  17.700 %      CO     35.9 PPM     CHX       .4 PPM
 NO     69.6 PPM  NO2     10.6 PPM  NOX    80.2 PPM (NO(NDIR) + NO2(NDUV))
 NO     70.7 PPM  NO2       .0 PPM  NOX    70.7 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   2.89                 CHX=    .05
               CHEMILUMINESCENCE NOX=   8.37,   NDIR + NDUV NOX=   9.50

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .012026
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.9920 %
   CHECK ON F/A RATIO- F/A = .012001 W/O O2, CALCULATED O2 = 17.835 %

SMOKE INDEX:X
SALTZMAN NOX = 89.3              PPM
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Figure 315. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at BIP = 92 psia.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 81, READING #    921
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE: 8-11-72                       READING WAS TAKEN AT 1987: 6 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.027 LB/SEC     AVG BURNER INLET TEMP   600. DEG F
AVG BURNER INLET PRES   62.6    PSIA      AVG BURNER OUTLET TEMP 1189. DEG F
AVG BURNER DELTA P       6.48    "HG      PRESSURE LOSS              5.26 %
OVERALL F/A RATIO      .00820  (F/P)      FUEL FLOW RATE            59.85 LB/HR
AIR LOAD FACTOR         1.0897            PATTERN FACTOR            .32129
BOT HOT SPOT: # 16 * 1273.  DEG F         MAX BOT / AVG BOT        1.1475
FUEL INLET TEMPERATURE   93.  DEG F       FUEL INLET PRESSURE       54.9   PSIA
HEAT LOADING PARAMETER   .17635E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1268.   6 1031. 15 1258. 19 1079. 24 1189. 27 1118. 36 1176.
ANNULUS 2    4 1102.   7 1258. 16 1273. 21 1058. 25 1126. 34 1080. 37 1137.
ANNULUS 3    5  969.  14 1251. 17 1199. 22 1049. 26 1019. 35 1037. 39  994.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          60.50    PSIA     TOTAL PRESSURE          60.61   PSIA
STATIC PRESSURE         60.13    PSIA     STATIC PRESSURE         60.41   PSIA
VELOCITY DELTA P          .76     "HG     VELOCITY DELTA P          .40    "HG
AIR TEMPERATURE          600.   DEG F     AIR TEMPERATURE          600.  DEG F
AIR VELOCITY          150.42 FT/SEC      AIR VELOCITY           108.99 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.216    "HG

AIR FLOW DATA: P-REF= 106.0 PSIA   DELTA P=25.63 "HG    T-REF=  72. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       222.      HZ     VOLUMETRIC FLOW RATE    9.68 GAL/HR
FUEL PRESSURE AT F/M   151.5     PSIA     FUEL TEMP AT F/M         93.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    57.37 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             59.62 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.38  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    1.403 %     O2   19.500 %     CO     495.0 PPM      CHX    185.0 PPM
 NO      3.4 PPM  NO2      2.4 PPM  NOX       5.8 PPM (NO(NDIR) + NO2(NDUV))
 NO      2.0 PPM  NO2      1.0 PPM  NOX       3.9 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  68.64                    CHX=  34.62
                   CHEMILUMINESCENCE NOX=    .77,   NDIR + NDUV NOX=    1.14

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .007489
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  96.8570 %
   CHECK ON F/A RATIO- F/A = .007819 W/O O2. CALCULATED O2 = 18.980 %

SMOKE INDEX: 2.51
SALTZMAN NOX = 3.06                PPM
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Figure 316. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at BOT = 1100°F.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 81, READING #     922
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE:  8-11-72                        READING WAS TAKEN AT 192815B HOURS

CYCLE POINT  7                                                 0 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.414 LB/SEC     AVG BURNER INLET TEMP    688. DEG F
AVG BURNER INLET PRES  60.1    PSIA      AVG BURNER OUTLET TEMP 1719. DEG F
AVG BURNER DELTA P      6.65    "HG      PRESSURE LOSS             3.43 %
OVERALL F/A RATIO     .01727  (F/A)      FUEL FLOW RATE          125.20 LB/HR
AIR LOAD FACTOR        1.4913            PATTERN FACTOR          .36134
BOT HOT SPOT: # 16 = 2124.  DEG F        MAX BOT / AVG BOT       1.2352
FUEL INLET TEMPERATURE  93.  DEG F       FUEL INLET PRESSURE       57.2  PSIA
HEAT LOADING PARAMETER  .37198E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1465.  6 1357. 15 1994. 19 1768. 24 2093. 27 2042. 36 1721.
ANNULUS 2  4 1535.  7 1411. 16 2124. 21 1612. 25 1987. 34 1617. 37 1603.
ANNULUS 3  5 1269. 14 2012. 17 2012. 22 1773. 28 1672. 30 1536. 39 1547.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE            62.01    PSIA   TOTAL PRESSURE          60.13   PSIA
STATIC PRESSURE           59.78    PSIA   STATIC PRESSURE         59.76   PSIA
VELOCITY DELTA P           .47     "HG    VELOCITY DELTA P          .74    "HG
AIR TEMPERATURE           689.  DEG F     AIR TEMPERATURE          688.  DEG F
AIR VELOCITY            118.22 FT/SEC     AIR VELOCITY           140.78 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.231    "HG

AIR FLOW DATA: P-UPS= 135.7 PSIA   DELTA P=25.40 "HG   T-REF=  71. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        462.      HZ    VOLUMETRIC FLOW RATE  20.23 GAL/HR
FUEL PRESSURE AT F/M   131.5    PSIA      FUEL TEMP AT F/M          94.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     58.01 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              59.00 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.53  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    3.108 %     O2  16.908 %      CO    184.5 PPM      CHX      2.1 PPM
 NO     64.4 PPM  NO2     10.2 PPM  NOX     74.6 PPM (NO(NDIR) + NO2(NDUV))
 NO     62.7 PPM  NO2      4.0 PPM  NOX     66.7 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   5.07                   CHX=     .10
                   CHEMILUMINESCENCE NOX=   6.24,   NDIR + NDUV NOX=    6.86

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .014008
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  90.7894 %
   CHECK ON F/A RATIO- F/A = .014044 W/O O2, CALCULATED O2 = 16.004 %

SMOKE INDEX: 1.33
SALTZMAN NOX = 79.1                  PPM
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Figure 317. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at BOT = 1700°F.

T63 COMBUSTION EXPERIMENTS - RIG B/U 67, TEST SERIES 61, READING # 923
T63 FINAL PRECHAMBER, MOD "B" RUNNING PARAMETRIC PERFORMANCE STUDIES.
TEST DATE: 8-11-72 READING WAS TAKEN AT 1950148 HOURS

CYCLE POINT 7

8 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	1.011 LB/SEC		AVG BURNER INLET TEMP	598. DEG F
AVG BURNER INLET PRES	60.3	PSIA	AVG BURNER OUTLET TEMP	1503. DEG F
AVG BURNER DELTA P	1.59	"HG	PRESSURE LOSS	1.28 %
OVERALL F/A RATIO	.01445	(F/P)	FUEL FLOW RATE	52.59 LB/HR
AIR LOAD FACTOR	.5451		PATTERN FACTOR	.37392
BOT HOT SPOT: # 27 = 1842.		DEG F	MAX BOT / AVG BOT	1.2252
FUEL INLET TEMPERATURE	92.	DEG F	FUEL INLET PRESSURE	56.5 PSIA

HEAT LOADING PARAMETER .15565E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID TEMP	ID TEMP	ID TEMP	ID TEMP	ID TEMP	ID TEMP	ID TEMP
ANNULUS 1	2 1343.	6 1298.	15 1687.	19 1544.	24 1825.	27 1842.	36 1458.
ANNULUS 2	4 1454.	7 1259.	16 1752.	21 1522.	25 1770.	34 1415.	37 1420.
ANNULUS 3	5 1213.	14 1534.	17 1637.	22 1547.	26 1492.	35 1316.	39 1281.

LEFT SIDE *** AIR INLET TUBE CONDITIONS *** RIGHT SIDE

TOTAL PRESSURE	60.29	PSIA	TOTAL PRESSURE	60.31	PSIA
STATIC PRESSURE	60.22	PSIA	STATIC PRESSURE	60.28	PSIA
VELOCITY DELTA P	.12	"HG	VELOCITY DELTA P	.08	"HG
AIR TEMPERATURE	597.	DEG F	AIR TEMPERATURE	598.	DEG F
AIR VELOCITY	50.83	FT/SEC	AIR VELOCITY	37.60	FT/SEC

DIFFERENTIAL PRESSURE ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.057 "HG

AIR FLOW DATA: P-METER 114.2 PSIA DELTA P= 5.93 "HG T-METER 71. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	195.	HZ	VOLUMETRIC FLOW RATE	8.49 GAL/HR
FUEL PRESSURE AT F/M	151.8	PSIA	FUEL TEMP AT F/M	92. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 59.51 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE 60.12 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 1.58 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2	2.841 %	O2	17.300 %	CO	46.5 PPM	CHX	.0 PPM
NO	69.1 PPM	NO2	0.7 PPM	NOX	69.9 PPM (NO(NDIR) + NO2(NDUV))		
NO	76.7 PPM	NO2	.0 PPM	NOX	74.7 PPM (CHEMILUMINESCENCE)		

EMISSIONS INDEX, LB/1000 LB FUEL: CO= 3.16 CHX= .00
CHEMILUMINESCENCE NOX= 8.32, NDIR + NDUV NOX= 10.82

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .013202
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.0720 %
CHECK ON F/A RATIO- F/A = .013308 W/O CP, CALCULATED O2 = 17.094 %

SMOKE INDEX: X
SALTZMAN NOX = 98/ PPM
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Figure 318. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at Airflow = 1 lb/sec.

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T63 COMBUSTOR EXPERIMENTS - RIG P/U 67, TEST SERIES 81, READING #    924
T63 FINAL PRECHAMBER, MOD "B"  RUNNING PARAMETRIC PERFORMANCE STUDIES,
TEST DATE:  8-11-72                        READING WAS TAKEN AT 2009: 4 HOURS

CYCLE POINT  7                                              0 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.809 LB/SEC     AVG BURNER INLET TEMP    601. DEG F
AVG BURNER INLET PRES  60.3    PSIA       AVG BURNER OUTLET TEMP 1497. DEG F
AVG BURNER DELTA P      13.49    "HG      PRESSURE LOSS            10.99 %
OVERALL F/A RATIO      .01350  (F/P)      FUEL FLOW RATE          137.12 LB/HR
AIR LOAD FACTOR        1.5180             PATTERN FACTOR           .26638
BOT HOT SPOT: # 14 = 1736.  DEG F         MAX BOT / AVG BOT        1.1594
FUEL INLET TEMPERATURE  93.  DEG F        FUEL INLET PRESSURE       55.5   PSIA
HEAT LOADING PARAMETER  .40605E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1449.   6 1289. 15 1681. 19 1396. 24 1730. 27 1574. 36 1502.
ANNULUS 2   4 1465.   7 1312. 16 1703. 21 1411. 25 1679. 34 1441. 37 1512.
ANNULUS 3   5 1264.  14 1736. 17 1575. 22 1466. 26 1497. 35 1424. 39 1297.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           60.22    PSIA    TOTAL PRESSURE          60.30   PSIA
STATIC PRESSURE          59.61    PSIA    STATIC PRESSURE         59.57   PSIA
VELOCITY DELTA P          1.22     "HG    VELOCITY DELTA P         1.49    "HG
AIR TEMPERATURE          601.   DEG F     AIR TEMPERATURE         601.   DEG F
AIR VELOCITY            191.58 FT/SEC     AIR VELOCITY           211.48 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]           -.182    "HG

AIR FLOW DATA: P-REF= 104.1 PSIA   DELTA P=54.84 "HG    T-REF=  70. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       506.      HZ     VOLUMETRIC FLOW RATE  22.15 GAL/HR
FUEL PRESSURE AT F/M   125.3    PSIA      FUEL TEMP AT F/M          94.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     53.63 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              58.23 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                13.40  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.205 %      O2  18.290 %      CO    119.9 PPM     CHX      1.2 PPM
 NO     23.2 PPM  NO2      9.3 PPM   NOX     32.5 PPM [NO(NDIR) + NO2(NDUV)]
 NO     23.6 PPM  NO2      9.8 PPM   NOX     33.4 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    8.67                  CHX=     .14
                   CHEMILUMINESCENCE NOX=   3.96,    NDIR + NDUV NOX=   3.86

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .010465
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7128 %
   CHECK ON F/A RATIO- F/A = .010603 W/O O2, CALCULATED O2 = 17.928 %

SMOKE INDEX: X
SALTZMAN NOX = 40.7              PPM
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Figure 319. Final Prechamber Liner Modification "B" on Wall Fuel Film Injection Parametric Test at Airflow = 3 lb/sec.

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T63 COMBUSTOR EXPERIMENTS - RIG P/U 67, TEST SERIES 82, READING #    925
T3 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE: 8-12-72                  READING WAS TAKEN AT 1043: 5 HOURS

CYCLE POINT  7                                      0 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.990 LB/SEC     AVG BURNER INLET TEMP   201. DEG F
AVG BURNER INLET PRES  58.9    PSIA       AVG BURNER OUTLET TEMP 1505. DEG F
AVG BURNER DELTA P      4.17    "HG       PRESSURE LOSS            3.47 %
OVERALL F/A RATIO     .01781  (F/M)       FUEL FLOW RATE         127.50 LB/HR
AIR LOAD FACTOR       .3577               PATTERN FACTOR         .46351
BOT HOT SPOT:  # 37 = 2110.   DEG F       MAX BOT / AVG BOT      1.4017
FUEL INLET TEMPERATURE  87.   DEG F       FUEL INLET PRESSURE     183.5  PSIA
HEAT LOADING PARAMETER   .38632E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP
ANNULUS 1   2 1274.   6 1071.  15 1769.  19 1346.  24 1549.  27 1539.  36 1879.
ANNULUS 2   4 1163.   7 1150.  16 1971.  21 1044.  25 1466.  34 1692.  37 2110.
ANNULUS 3   5 1045.  14 1822.  17 1873.  22 1143.  26 1377.  35 1782.  39 1545.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          58.92    PSIA    TOTAL PRESSURE           58.95   PSIA
STATIC PRESSURE         58.78    PSIA    STATIC PRESSURE          58.80   PSIA
VELOCITY DELTA P          .29     "HG    VELOCITY DELTA P           .29    "HG
AIR TEMPERATURE         201.    DEG F    AIR TEMPERATURE          201.   DEG F
AIR VELOCITY            73.72 FT/SEC     AIR VELOCITY             74.44 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.064    "HG

AIR FLOW DATA: P-REF= 135.6 PSIA   DELTA P=25.91 "HG   T-REF=  92. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      469.      HZ     VOLUMETRIC FLOW RATE  20.53 GAL/HR
FUEL PRESSURE AT F/M  290.2     PSIA     FUEL TEMP AT F/M         87.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    56.89 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             58.63 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.13  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2    3.522 %     O2  16.250 %     CO    187.7 PPM     CHX      2.0 PPM
 NO     23.2 PPM  NO2     12.3 PPM  NOX     35.6 PPM [NO(NDIR, + NO2(NDUV)]
 NO     26.5 PPM  NO2      8.8 PPM  NOX     35.3 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.37                 CHX=    .17
                 CHEMILUMINESCENCE NOX=   3.20,    NDIR + NDUV NOX=   3.23

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .016695
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7229 %
   CHECK ON F/A RATIO- F/A = .016827 W/O O2, CALCULATED O2 = 16.088 %

SMOKE INDEX: 34.6
SALTZMAN NOX =  43.1          PPM
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Figure 320. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at BIT = 200°F.

TABLE LXXX. PARAMETRIC TEST RESULTS FOR FINAL PRECHAMBER MODIFICATION "B" COMBUSTOR LINER

Reading Number	Airflow (lb/sec)	BIT (°F)	BIP (psia)	BOT (°F)	F/A	ΔP (%)	Flow Factor	Exhaust Temp. Profile T_{max}/T_{avg}	Exhaust Temp. Profile Pattern Factor	Exhaust Emissions Constituent CO (ppm)	Exhaust Emissions Constituent C_xH_y (ppm)	Exhaust Emissions Constituent NO_x (ppm)	Exhaust Emissions Constituent Smoke Index	Chemical Analysis Comb. Eff. (%)	Chemical Analysis F/A
Full Fuel Film Injection															
923	1.011	59[illegible]	60.3	1503	.01445	1.30	.545	1.2252	.3739	46.5	.0	80.9	-	99.47	.01325
917	[illegible]	600	60.4	1502	.01387	5.47	1.093	1.1620	.2698	91.9	2.7	50.8	2.87	99.77	.01171
924	2.609	601	[illegible]	1497	.01356	10.99	1.518	1.1598	.2684	119.9	1.2	32.5	-	99.71	.01944
91[illegible]	2.031	[illegible]	59.4	1482	.01583	4.23	1.004	1.4142	.5666	200.7	10.8	37.9	7.17	99.58	.01465
917	2.023	[illegible]	60.4	1502	.01387	5.47	1.093	1.1620	.2698	91.9	2.7	50.8	2.87	99.77	.01171
91[illegible]	2.055	1002	60.0	[illegible]	.00823	7.51	1.308	1.0841	.2512	22.1	1.0	24.9	-	99.99	.00823
919	2.031	597	32.5	1504	.01425	21.48	2.041	1.1791	.2973	651.5	51.0	17.9	-	97.78	.01093
917	2.023	600	60.4	1502	.01387	5.47	1.093	1.1620	.2698	91.9	2.7	50.8	2.87	99.77	.01171
920	2.035	601	92.7	1519	.01359	1.99	.715	1.2302	.3625	35.9	.4	80.2	-	99.83	.01263
921	2.027	600	60.5	1109	.00920	5.26	1.090	1.1475	.4213	695.0	185.0	5.8	2.51	94.66	.00761
917	2.024	600	60.4	1502	.01387	5.47	1.093	1.1620	.2698	91.9	2.7	50.9	2.87	99.77	.01171
922	2.014	600	60.1	1719	.01727	5.43	1.091	1.2352	.3613	104.9	2.1	74.6	1.33	99.79	.01468
Pressure Atomizer Injection															
933	1.007	599	59.9	1507	.01391	1.05	.547	1.1921	.3189	28.2	.0	72.2	51.19	99.92	.01438
926	2.033	601	59.8	1498	.01344	5.42	1.107	1.2050	.3425	59.6	.2	43.8	22.73	99.87	.01256
928	2.832	596	60.0	1506	.01366	10.76	1.534	1.1519	.2991	62.0	.1	36.1	1.56	99.87	.01271
925	1.990	201	58.9	1505	.01791	3.47	.868	1.4017	.6635	187.7	2.0	35.6	39.60	99.72	.01679
926	2.033	601	59.8	1498	.01344	5.42	1.207	1.2050	.3425	59.6	.2	43.8	22.73	99.87	.01256
927	2.018	1001	60.1	1503	.00847	7.00	1.283	1.1004	.3007	16.6	.8	50.6	36.60	99.90	.00850
929	1.994	600	32.2	1497	.01402	21.98	2.019	1.2295	.3830	228.1	.0	19.9	.33	99.58	.01242
926	2.033	601	59.8	1498	.01344	5.42	1.107	1.2050	.3425	59.6	.2	43.8	22.73	99.87	.01256
932	2.070	600	91.2	1506	.01318	2.08	.7213	1.2035	.3384	30.4	.4	60.0	67.27	99.91	.01291
930	[illegible]55	600	60.4	1101	.00740	4.97	1.108	1.1365	.2998	312.5	10.4	20.3	56.67	98.84	.00759
926	2.033	601	59.8	1498	.01344	5.42	1.107	1.2050	.3425	59.6	.2	43.8	22.73	99.87	.01256
931	2.051	601	59.6	1725	.01711	5.09	1.121	1.2189	.3359	116.2	.2	81.8	32.46	99.80	.01610

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T63 COMBUSTOR EXPERIMENTS - RIG 6/U 67, TEST SERIES 82, READING #     926
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE:  8-12-72                       READING WAS TAKEN AT 1:18: 3 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.033 LB/SEC    AVG BURNER INLET TEMP    601. DEG F
AVG BURNER INLET PRES   59.8   PSIA      AVG BURNER OUTLET TEMP 1498. DEG F
AVG BURNER DELTA P       6.60   "HG      PRESSURE LOSS            5.42 %
OVERALL F/A RATIO       .01344  (F/M)    FUEL FLOW RATE          98.34 LB/HR
AIR LOAD FACTOR         1.1067           PATTERN FACTOR          .34246
BOT HOT SPOT:  # 16 = 1805.  DEG F       MAX BOT / AVG BOT       1.2050
FUEL INLET TEMPERATURE  93.  DEG F       FUEL INLET PRESSURE     134.8  PSIA
HEAT LOADING PARAMETER  .29330E+07 PTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1372.  6 1317. 15 1752. 19 1485. 24 1616. 27 1565. 36 1747.
ANNULUS 2    4 1325.  7 1333. 16 1805. 21 1299. 25 1563. 34 1468. 37 1683.
ANNULUS 3    5 1276. 14 1645. 17 1655. 22 1325. 26 1447. 35 1464. 39 1315.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          59.78    PSIA    TOTAL PRESSURE          59.87   PSIA
STATIC PRESSURE         59.42    PSIA    STATIC PRESSURE         59.65   PSIA
VELOCITY DELTA P          .75     "HG    VELOCITY DELTA P          .46    "HG
AIR TEMPERATURE          601.   DEG F    AIR TEMPERATURE          601.  DEG F
AIR VELOCITY           154.16  FT/SEC    AIR VELOCITY           116.85 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.176    "HG

AIR FLOW DATA: P-REF= 105.2 PSIA    DELTA P=27.51 "HG    T-REF=  97. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      363.     HZ      VOLUMETRIC FLOW RATE   15.87 GAL/HR
FUEL PRESSURE AT F/M   296.0    PSIA     FUEL TEMP AT F/M         92.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE      56.58 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               58.63 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  6.52  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.650 %     O2   17.500 %     CO     59.6 PPM     CHX       .2 PPM
 NO     36.6 PPM   NO2      7.2 PPM  NOX    43.8 PPM [NO(NDIR) + NO2(NDUV)]
 NO     39.2 PPM   NO2      1.9 PPM  NOX    41.1 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=     4.38              CHX=      .02
                   CHEMILUMINESCENCE NOX=  4.93,    NDIR + NDUV NOX=  5.25

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .012561
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8702 %
   CHECK ON F/A RATIO- F/A = .012676 W/O O2, CALCULATED O2 = 17.385 %

SMOKE INDEX: 22.73
SALTZMAN NOX = 52.9                    PPM
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Figure 321. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test BIT = 200°F.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 82, READING #     927
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE:  8-12-72                    READING WAS TAKEN AT 1154:48 HOURS

CYCLE POINT  7                                         0 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.018 LB/SEC    AVG BURNER INLET TEMP  1001. DEG F
AVG BURNER INLET PRES  60.1    PSIA      AVG BURNER OUTLET TEMP 1503. DEG F
AVG BURNER DELTA P      8.56    "HG      PRESSURE LOSS             7.00 %
OVERALL F/A RATIO     .00837  (F/M)      FUEL FLOW RATE           60.82 LB/HR
AIR LOAD FACTOR       1.2828             PATTERN FACTOR          .30074
HOT HOT SPOT: # 16 = 1654.  DEG F        MAX BOT / AVG BOT       1.1004
FUEL INLET TEMPERATURE  98.  DEG F       FUEL INLET PRESSURE       87.6  PSIA
HEAT LOADING PARAMETER  .18054E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1459.   6 1437. 15 1643. 19 1496. 24 1578. 27 1493. 36 1631.
ANNULUS 2   4 1454.   7 1455. 16 1654. 21 1427. 25 1515. 34 1488. 37 1535.
ANNULUS 3   5 1408. 14 1571. 17 1583. 22 1437. 26 1449. 35 1473. 39 1380.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          64.07   PSIA     TOTAL PRESSURE          60.14   PSIA
STATIC PRESSURE         59.67   PSIA     STATIC PRESSURE         59.71   PSIA
VELOCITY DELTA P          .82    "HG     VELOCITY DELTA P          .87    "HG
AIR TEMPERATURE         1001.  DEG F     AIR TEMPERATURE         1001.  DEG F
AIR VELOCITY          184.34 FT/SEC      AIR VELOCITY          189.88 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]            -.142   "HG

AIR FLOW DATA: P-REF= 105.0 PSIA   DELTA P=27.30 "HG   T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       226.     HZ     VOLUMETRIC FLOW RATE     9.84 GAL/HR
FUEL PRESSURE AT F/M   316.2    PSIA     FUEL TEMP AT F/M          96.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   55.90 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            58.79 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               8.49  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   1.778 %     O2   18.690 %     CO      16.6 PPM     CHX        .0 PPM
 NO    46.4 PPM   NO2      4.2 PPM  NOX     50.6 PPM (NO(NDIR) + NO2(NDUV))
 NO    47.0 PPM   NO2       .0 PPM  NOX     47.0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    1.93                 CHX=     .14
                   CHEMILUMINESCENCE NOX=  8.99,   NDIR + NDUV NOX=    9.68

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:      .008580
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.9023 %
   CHECK ON F/A RATIO- F/A = .008532 W/O O2, CALCULATED O2 = 18.522 %

SMOKE INDEX: 36.8
SALTZMAN NOX = 52.5              PPM
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Figure 322. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at Nominal Conditions.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 82, READING #    928
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE:  8-12-72                     READING WAS TAKEN AT 1223:31 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW         2.832 LB/SEC    AVG BURNER INLET TEMP   596. DEG F
AVG BURNER INLET PRES  60.0   PSIA      AVG BURNER OUTLET TEMP 1508. DEG F
AVG BURNER DELTA P     13.14   "HG      PRESSURE LOSS          10.76 %
OVERALL F/A RATIO     .01366  (F/M)     FUEL FLOW RATE        139.24 LB/HR
AIR LOAD FACTOR       1.5341            PATTERN FACTOR         .29909
BOT HOT SPOT:  # 16 = 1782.  DEG F      MAX BOT / AVG BOT     1.1810
FUEL INLET TEMPERATURE  98.  DEG F      FUEL INLET PRESSURE    202.8  PSIA
HEAT LOADING PARAMETER  .41437E+07 BTU/HOUR/ATM/CUBIC FOOT

               **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1424.  6 1335. 15 1746. 19 1445. 24 1648. 27 1509. 36 1700.
ANNULUS 2  4 1341.  7 1372. 16 1782. 21 1326. 25 1548. 34 1505. 37 1733.
ANNULUS 3  5 1310. 14 1677. 17 1655. 22 1345. 26 1424. 35 1532. 39 1321.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***         RIGHT SIDE
TOTAL PRESSURE          59.86   PSIA    TOTAL PRESSURE         60.06   PSIA
STATIC PRESSURE         59.31   PSIA    STATIC PRESSURE        59.64   PSIA
VELOCITY DELTA P         1.13    "HG    VELOCITY DELTA P         .84    "HG
AIR TEMPERATURE         596.  DEG F     AIR TEMPERATURE         595.  DEG F
AIR VELOCITY          184.18 FT/SEC     AIR VELOCITY          158.71 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))    -.402    "HG

AIR FLOW DATA: P-REF= 143.0 PSIA   DELTA P=60.86 "HG   T-REF= 101. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      515.     HZ     VOLUMETRIC FLOW RATE  22.55 GAL/HR
FUEL PRESSURE AT F/M  290.4    PSIA     FUEL TEMP AT F/M         97.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    53.50 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             57.57 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               12.94  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2   2.650 %    O2  17.250 %     CO     62.0 PPM     CHX     .1 PPM
 NO    28.8 PPM  NO2     7.2 PPM  NOX    36.1 PPM (NO(NDIR) + NO2(NDUV))
 NO    31.4 PPM  NO2     1.9 PPM  NOX    33.4 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   4.45                CHX=    .01
               CHEMILUMINESCENCE NOX=    3.93,    NDIR + NDUV NOX=   4.25

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .012710
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8717 %
   CHECK ON F/A RATIO- F/A = .012677 W/O O2, CALCULATED O2 = 17.305 %

SMOKE INDEX: 1.56
SALTZMAN NOX = 38.7                PPM
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Figure 323. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at Airflow = 3 lb/sec.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 62, READING # 929
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE: 8-12-72 READING WAS TAKEN AT 124645 HOURS

CYCLE POINT 7 0 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW 1.994 LB/SEC | AVG BURNER INLET TEMP 600. DEG F
AVG BURNER INLET PRES 32.2 PSIA | AVG BURNER OUTLET TEMP 1497. DEG F
AVG BURNER DELTA P 14.39 "HG | PRESSURE LOSS 21.98 %
OVERALL F/A RATIO .01402 (F/A) | FUEL FLOW RATE 100.67 LB/HR
AIR LOAD FACTOR 2.0187 | PATTERN FACTOR .38301
BOT HOT SPOT: # 16 = 1841. DEG F | MAX BOT / AVG BOT 1.2295
FUEL INLET TEMPERATURE 100. DEG F | FUEL INLET PRESSURE 107.2 PSIA
HEAT LOADING PARAMETER .55854E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1319.	6	1275.	15	1724.	19	1452.	24	1669.	27	1489.	36	1691.
ANNULUS 2	4	1259.	7	1310.	16	1841.	21	1261.	25	1535.	34	1476.	37	1731.
ANNULUS 3	5	1272.	14	1731.	17	1718.	22	1373.	26	1403.	35	1542.	39	1356.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE			RIGHT SIDE		
TOTAL PRESSURE	32.05	PSIA	TOTAL PRESSURE	32.27	PSIA
STATIC PRESSURE	31.49	PSIA	STATIC PRESSURE	31.75	PSIA
VELOCITY DELTA P	1.15	"HG	VELOCITY DELTA P	1.06	"HG
AIR TEMPERATURE	600.	DEG F	AIR TEMPERATURE	600.	DEG F
AIR VELOCITY	255.26	FT/SEC	AIR VELOCITY	243.79	FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.432 "HG

AIR FLOW DATA: P-REF= 104.6 PSIA DELTA P=26.83 "HG T-REF= 102. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY 373. HZ | VOLUMETRIC FLOW RATE 16.31 GAL/HR
FUEL PRESSURE AT F/M 316.4 PSIA | FUEL TEMP AT F/M 98. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 25.09 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 29.71 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 14.17 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1
CO2 2.550 % O2 17.200 % CO 220.1 PPM CHX .0 PPM
NO 12.7 PPM NO2 7.2 PPM NOX 19.9 PPM (NO(NDIR) + NO2(NDUV))
NO 16.1 PPM NO2 3.5 PPM NOX 19.6 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 15.95 CHX= .00
CHEMILUMINESCENCE NOX= 2.25, NDIR + NDUV NOX= 2.29

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .012419
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.5765 %
CHECK ON F/A RATIO- F/A = .012265 W/O O2, CALCULATED O2 = 17.430 %

SMOKE INDEX: 0.33
SALTZMAN NOX = 19.2 PPM

Figure 324. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at BIP = 32 psia.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 82, READING #    938
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE: 8-12-72                       READING WAS TAKEN AT 13:2: 7 HOURS

CYCLE POINT  7                                             0 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.055 LB/SEC    AVG BURNER INLET TEMP   600. DEG F
AVG BURNER INLET PRES  60.4    PSIA      AVG BURNER OUTLET TEMP 1101. DEG F
AVG BURNER DELTA P      6.11    "HG      PRESSURE LOSS            4.97 %
OVERALL F/A RATIO      .00740  (F/M)     FUEL FLOW RATE          54.78 LB/HR
AIR LOAD FACTOR        1.1075            PATTERN FACTOR          .29977
BOT HOT SPOT:  # 16 = 1251.  DEG F       MAX BOT / AVG BOT      1.1365
FUEL INLET TEMPERATURE 101.  DEG F       FUEL INLET PRESSURE      79.5  PSIA
HEAT LOADING PARAMETER  .16186E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1060.  6 1054. 15 1234. 19 1053. 24 1164. 27 1092. 36 1337.
ANNULUS 2   4 1044.  7 1071. 16 1251. 21 1007. 25 1117. 34 1094. 37 1138.
ANNULUS 3   5 1013. 14 1181. 17 1170. 22 1017. 26 1048. 35 1079. 39  986.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           60.33    PSIA    TOTAL PRESSURE          60.45   PSIA
STATIC PRESSURE          60.00    PSIA    STATIC PRESSURE         60.17   PSIA
VELOCITY DELTA P           .67     "HG    VELOCITY DELTA P          .57    "HG
AIR TEMPERATURE          600.   DEG F     AIR TEMPERATURE         599.   DEG F
AIR VELOCITY            140.96 FT/SEC     AIR VELOCITY            129.74 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.257    "HG

AIR FLOW DATA: P-REF= 104.9 PSIA   DELTA P=28.66 "HG   T-REF= 104. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       204.      HZ     VOLUMETRIC FLOW RATE   8.88 GAL/HR
FUEL PRESSURE AT F/M   337.4     PSIA     FUEL TEMP AT F/M       100.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   57.39 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              59.31 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 5.08  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    1.630 %     O2  18.600 %      CO    312.8 PPM     CHX     10.4 PPM
 NO       8.4 PPM  NO2      11.9 PPM  NOX     20.3 PPM (NO(NDIR) + NO2(NDUV))
 NO       9.5 PPM  NO2      11.1 PPM  NOX     20.6 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  41.11                    CHX=   2.16
                 CHEMILUMINESCENCE NOX=   4.46,    NDIR + NDUV NOX=    4.39

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .007593
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.0402 %
   CHECK ON F/A RATIO- F/A = .007596 W/O O2, CALCULATED O2 = 18.042 %

SMOKE INDEX: 56.67
SALTZMAN NOX = 21.2                PPM
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Figure 325. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at BOT = 1100°F.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 82, READING #     931
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE:  8-12-72                         READING WAS TAKEN AT 133249 HOURS

CYCLE POINT  7                                              0 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW        2.051 LB/SEC     AVG BURNER INLET TEMP   601. DEG F
AVG BURNER INLET PRES  59.6    PSIA     AVG BURNER OUTLET TEMP 1725. DEG F
AVG BURNER DELTA P      6.18    "HG     PRESSURE LOSS             5.09 %
OVERALL F/A RATIO     .01711  (F/M)     FUEL FLOW RATE          126.30 LB/HR
AIR LOAD FACTOR       1.1208            PATTERN FACTOR          .33589
BOT HOT SPOT:  # 16 = 2103.  DEG F      MAX BOT / AVG BOT       1.2189
FUEL INLET TEMPERATURE 101.  DEG F      FUEL INLET PRESSURE     189.0  PSIA
HEAT LOADING PARAMETER  .37820E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1651.  6 1516. 15 1997. 19 1870. 24 1915. 27 1715. 36 1942.
ANNULUS 2   4 1638.  7 1574. 16 2103. 21 1442. 25 1781. 34 1883. 37 1951.
ANNULUS 3   5 1455. 14 1812. 17 2006. 22 1469. 26 1646. 35 1625. 39 1443.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE            59.52   PSIA   TOTAL PRESSURE          59.65   PSIA
STATIC PRESSURE           59.10   PSIA   STATIC PRESSURE         59.44   PSIA
VELOCITY DELTA P           .85     "HG   VELOCITY DELTA P         .43     "HG
AIR TEMPERATURE           601.  DEG F    AIR TEMPERATURE         601.   DEG F
AIR VELOCITY            160.62 FT/SEC    AIR VELOCITY          113.71 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.276    "HG

AIR FLOW DATA: P-REF= 104.5 PSIA   DELTA P=28.67 "HG   T-REF= 104. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      468.      HZ     VOLUMETRIC FLOW RATE  20.40 GAL/HR
FUEL PRESSURE AT F/M  305.4     PSIA     FUEL TEMP AT F/M        101.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     56.55 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              58.40 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.04  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    3.313 %      O2   16.000 %      CO    116.2 PPM      CHX        .2 PPM
 NO     66.6 PPM   NO2     15.2 PPM   NOX     81.8 PPM (NO(NDIR) + NO2(NDUV))
 NO     77.7 PPM   NO2      3.0 PPM   NOX     80.8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    6.60                   CHX=     .01
                  CHEMILUMINESCENCE NOX=    7.62,    NDIR + NDUV NOX=    7.72

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .016097
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7996 %
   CHECK ON F/A RATIO- F/A = .015814 W/O O2, CALCULATED O2 = 16.378 %

SMOKE INDEX: 32.46
SALTZMAN NOX = 78                 PPM
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Figure 326. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at BOT = 1700°F.

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T63 COMBUSTOR EXPERIMENTS - RIG E/U 67, TEST SERIES 82, READING #    932
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE: 8-12-72                       READING WAS TAKEN AT 1355134 HOURS

CYCLE POINT  7                                          0 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.020 LB/SEC   AVG BURNER INLET TEMP   600. DEG F
AVG BURNER INLET PRES  91.2    PSIA     AVG BURNER OUTLET TEMP 1506. DEG F
AVG BURNER DELTA P      3.87    "HG     PRESSURE LOSS            2.08 %
OVERALL F/A RATIO     .01318  (F/M)     FUEL FLOW RATE          95.82 LB/HR
AIR LOAD FACTOR        .7213            PATTERN FACTOR         .33841
BOT HOT SPOT:  # 16 = 1813.  DEG F      MAX BOT / AVG BOT      1.2035
FUEL INLET TEMPERATURE 103.  DEG F      FUEL INLET PRESSURE     166.4  PSIA
HEAT LOADING PARAMETER  .18749E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1333.  6 1298. 15 1758. 19 1420. 24 1646. 27 1583. 36 1794.
ANNULUS 2   4 1288.  7 1325. 16 1813. 21 1320. 25 1582. 34 1490. 37 1722.
ANNULUS 3   5 1254. 14 1663. 17 1683. 22 1346. 26 1462. 35 1504. 39 1362.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           91.18    PSIA   TOTAL PRESSURE          91.20   PSIA
STATIC PRESSURE          90.92    PSIA   STATIC PRESSURE         91.01   PSIA
VELOCITY DELTA P           .54     "HG   VELOCITY DELTA P          .40    "HG
AIR TEMPERATURE           600.   DEG F   AIR TEMPERATURE          600.  DEG F
AIR VELOCITY            102.76 FT/SEC    AIR VELOCITY            88.09 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.039    "HG

AIR FLOW DATA: P-REF= 164.5 PSIA    DELTA P=27.78 "HG    T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       356.      HZ     VOLUMETRIC FLOW RATE  15.86 GAL/HR
FUEL PRESSURE AT F/M   315.0     PSIA     FUEL TEMP AT F/M        102.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   89.29 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                90.50 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   3.85  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   2.050 %     O2  16.900 %     CO     30.4 PPM     CHX      .4 PPM
 NO    51.6 PPM  NO2      8.5 PPM  NOX     60.0 PPM (NO(NDIR) + NO2(NDUV))
 NO    52.9 PPM  NO2      2.0 PPM  NOX     54.8 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   2.26                 CHX=     .04
                  CHEMILUMINESCENCE NOX=   6.70,    NDIR + NDUV NOX=    7.33

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .012900
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.9112 %
   CHECK ON F/A RATIO- F/A = .012663 W/O O2, CALCULATED O2 = 17.306 %

SMOKE INDEX: 67.27
SALTZMAN NOX = 59.4                PPM
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Figure 327. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at BIP = 92 psia.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 67, TEST SERIES 82, READING #    933
T63 FINAL PRECHAMBER MOD "B" - PARAMETRIC STUDY ON PRESSURE NOZZLE.
TEST DATE:  8-12-72                        READING WAS TAKEN AT 1421153 HOURS

CYCLE POINT  7                                            0 % POWER SETTING

                      ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.007 LB/SEC     AVG BURNER INLET TEMP   599. DEG F
AVG BURNER INLET PRES  59.9    PSIA      AVG BURNER OUTLET TEMP 1507. DEG F
AVG BURNER DELTA P      1.28     "HG      PRESSURE LOSS             1.05 %
OVERALL F/A RATIO      .01391  (F/F)      FUEL FLOW RATE           50.40 LB/HR
AIR LOAD FACTOR         .5469             PATTERN FACTOR          .31004
BOT HOT SPOT: # 16 = 1796.  DEG F         MAX BOT / AVG BOT       1.1921
FUEL INLET TEMPERATURE 104.  DEG F        FUEL INLET PRESSURE      77.6  PSIA
HEAT LOADING PARAMETER  .15018E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1367.  6 1334. 15 1730. 19 1573. 24 1635. 27 1532. 36 1698.
ANNULUS 2   4 1428.  7 1346. 16 1796. 21 1342. 25 1557. 34 1539. 37 1689.
ANNULUS 3   5 1262. 14 1522. 17 1711. 22 1369. 26 1484. 35 1456. 39 1325.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          59.87    PSIA    TOTAL PRESSURE          59.90   PSIA
STATIC PRESSURE         59.74    PSIA    STATIC PRESSURE         59.83   PSIA
VELOCITY DELTA P          .28     "HG    VELOCITY DELTA P          .13    "HG
AIR TEMPERATURE         599.  DEG F      AIR TEMPERATURE         599.  DEG F
AIR VELOCITY            91.04 FT/SEC     AIR VELOCITY            63.23 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.055    "HG

AIR FLOW DATA: P-REF= 166.9 PSIA    DELTA P= 6.35 "HG    T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      188.      HZ     VOLUMETRIC FLOW RATE    8.10 GAL/HR
FUEL PRESSURE AT F/M  343.7    PSIA      FUEL TEMP AT F/M        103.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   59.26 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            59.00 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               1.25  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    2.953 %     O2  16.500 %     CO     20.2 PPM     CHX       .0 PPM
 NO     63.7 PPM  NO2      8.5 PPM  NOX    72.9 PPM (NO(NDIR) + NO2(NDUV))
 NO     64.7 PPM  NO2      1.0 PPM  NOX    65.7 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   1.98                    CHX=    .00
                  CHEMILUMINESCENCE NOX=   7.60.    NDIR + NDUV NOX=   8.36

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .014348
CALCULATED COMBUSTION EF  CIENCY FROM CHEMICAL ANALYSIS:  99.9218 %
   CHECK ON F/A RATIO- F/A = .014096 W/O O2, CALCULATED O2 = 16.004 %

SMOKE INDEX: 57.19
SALTZMAN NOX = 65.1                PPM
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Figure 328. Final Prechamber Liner Modification "B" on Pressure Atomizer Injection Parametric Test at Airflow = 1 lb/sec.

improved due to the enrichment of the reaction zone, since the reaction-zone-holes air admission rate was 25% of the swirler air rate, and by maintaining a strong swirl in the reaction zone, which had been dissipated to some extent by the normal injecting air jets through the reaction-zone holes. The stronger vortex would then transfer more combustion gases upstream to the fuel film, increasing the vaporization gas temperature, and thus the vaporization heat transfer. Table LXXXI is a summary of the emission performance of Final Prechamber Combustor Modifications "B", "C", and "D". The details of the Modification "C" nonregenerative test results are presented in Figure 329 through 333. The closing of the reaction-zone holes did increase the combustor pressure loss an additional 1%, to an average of 6.62% for the five operating conditions tested.

This change to the Prechamber combustor had no effect on the hydrocarbon concentrations the combustor produced; see Figure 334. Once again, the exhaust temperature profile at the high power operating conditions was too poor to permit the combustor to operate without damaging the exhaust instrumentation. Figure 335 shows that the change in Modification "C" did reduce the carbon monoxide concentration at idle but not at the higher power conditions. The NO_x concentrations plotted in Figure 336 show the improvement in the Prechamber Modification "C" combustor at middle power conditions. The CO vs NO_x curve for this configuration is plotted in Figure 337. This curve clearly shows the Modification "C" improvement in emissions at the 25% and 40% power conditions. Smoke was further reduced, as shown in Figure 338. This configuration was the first time smoke reductions were obtained that even approached those obtained in the preliminary Prechamber combustor. The exhaust temperature profile, Figure 339, although slightly improved in Modification "C", was still a severe problem. The degrading profile trend seen at 75% power conditions continued when rig conditions were increased toward maximum power, thus requiring that data for that point be aborted. After the wall fuel film data were obtained, the combustor was removed from the test rig and no pressure atomizer fuel injection mode data were taken on Modification "C".

Modification "D"

The final change to the Final Prechamber combustor was fabricating a centerbody and attaching it to the swirler vane hub band. The Preliminary Prechamber combustor used a vaporizer tube centerbody, but to incorporate the pressure atomizer fuel injector, the centerbody was not included in the previous Final Prechamber designs. The test rig data for Modification "D" are presented in Figures 340 through 344 and summarized in Table LXXXI. A poor exhaust temperature profile on this combustor, as in most of the previous configurations, required that the testing be restricted to only the lowest five operating conditions.

TABLE LXXXI. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF FINAL PRECHAMBER COMBUSTORS OPERATING ON WALL FUEL FILM INJECTION (1) MODIFICATION "B", (2) MODIFICATION "C", AND (3) MODIFICATION "D"

	Cycle Point					
	1	6	5	4	3	2
I. Final Prechamber, Mod. "B" - Wall Film						
A. Emissions						
CO, (ppm)	619.2	289.6	127.5	166.8	175.0	NO DATA TAKEN
H/C, (ppm)	140.0	40.0	9.8	7.2	2.1	
NO_x, (On-Line, NDIR & NDUV) (ppm)	12.2	17.3	27.1	35.5	51.6	
NO_x, (On-Line, CL) (ppm)	12.0	18.3	27.5	41.1	52.9	
NO_x, (Saltzman) (ppm)	10.4	19.6	30.3	39.9	55.9	
Smoke Number	0.10	1.82	0.96	0.11	3.26	
B. Pressure Loss (%)	5.98	5.15	5.92	5.79	5.81	
C. Temp. Profile (T_{max}/T_{avg})	1.441	1.357	1.277	1.290	1.274	

	1	6	5	4	3	2
II. Final Prechamber Mod. "C" Wall Fuel Film						
A. Emissions						
CO, (ppm)	457.9	142.9	158.7	160.7	170.9	NO DATA TAKEN
H/C, (ppm)	135.0	26.0	17.6	7.2	1.3	
NO_x, (On-Line, NDIR & NDUV) (ppm)	13.1	13.9	19.5	29.8	49.1	
NO_x, (On-Line, CL) (ppm)	13.0	15.6	25.1	40.2	43.0	
NO_x, (Saltzman) (ppm)	10.2	12.4	25.4	42.9	58.1	
Smoke Number	2.49	0.29	2.36	0.06	0.00	
B. Pressure Loss (%)	5.74	6.62	7.18	6.95	6.62	
C. Temp. Profile (T_{max}/T_{avg})	1.301	1.283	1.255	1.253	1.307	

	1	6	5	4	3	2
III. Final Prechamber - Mod. "D" Wall Fuel Film						
A. Emissions						
CO, (ppm)	426.5	185.5	129.4	156.7	156.7	NO DATA TAKEN
H/C, (ppm)	85.0	15.0	4.4	.7	.2	
NO_x, (On-Line, NDIR & NDUV) (ppm)	16.7	16.7	25.4	40.0	57.4	
NO_x, (On-Line, CL) (ppm)	13.5	18.1	27.5	39.2	50.9	
NO_x, (Saltzman) (ppm)	12.4	19.2	32.6	38.2	66.5	
Smoke Number	.01	.00	.00	.00	.00	
B. Pressure Loss (%)	6.14	6.72	6.78	6.67	6.15	
C. Temp. Profile (T_{max}/T_{avg})	1.361	1.294	1.230	1.230	1.317	

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 68, TEST SERIES 83, READING #    934
T63 FINAL PRECHAMBER MOD "C" - ON FILM NOZZLE @ STD T63 INLET CONDITIONS
TEST DATE:  8-14-72                        READING WAS TAKEN AT 1413:12 HOURS

CYCLE POINT  1                                            10 % POWER SETTING

                 ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          1.444 LB/SEC    AVG BURNER INLET TEMP    300. DEG F
AVG BURNER INLET PRES   44.3    PSIA     AVG BURNER OUTLET TEMP 1017. DEG F
AVG BURNER DELTA P       5.18    "HG     PRESSURE LOSS             5.74 %
OVERALL F/A RATIO       .01394  (F/P)    FUEL FLOW RATE           72.63 LB/HR
AIR LOAD FACTOR         1.1472           PATTERN FACTOR            .42251
BOT HOT SPOT:  # 24 = 1362.  DEG F       MAX BOT / AVG BOT        1.3813
FUEL INLET TEMPERATURE   93.  DEG F      FUEL INLET PRESSURE       40.9  PSIA
HEAT LOADING PARAMETER   .29246E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2  951.  6  808. 15 1283. 19 1215. 24 1362. 27 1026. 36 1093.
ANNULUS 2    4  997.  7  832. 16 1356. 21 1062. 25 1056. 34  981. 37 1079.
ANNULUS 3    5  774. 14 1386. 17 1251. 22 1158. 26  887. 35  907. 39  850.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***               RIGHT SIDE
TOTAL PRESSURE          44.31    PSIA    TOTAL PRESSURE          44.32   PSIA
STATIC PRESSURE         44.03    PSIA    STATIC PRESSURE         44.14   PSIA
VELOCITY DELTA P          .58     "HG    VELOCITY DELTA P          .37    "HG
AIR TEMPERATURE          300.   DEG F    AIR TEMPERATURE          300.   DEG F
AIR VELOCITY           129.49 FT/SEC     AIR VELOCITY           103.73 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.024    "HG

AIR FLOW DATA: P-REF= 105.1 PSIA   DELTA P= 1.60 "HG    T-REF= 103. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      269.      HZ     VOLUMETRIC FLOW RATE  11.72 GAL/HR
FUEL PRESSURE AT F/M  233.4     PSIA     FUEL TEMP AT F/M        92.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    41.77 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             43.59 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.17  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2    1.817 %     O2  18.900 %     CO    457.9 PPM     CHX   135.0 PPM
NO       4.2 PPM  NO2     8.9 PPM  NOX     13.1 PPM (NO(NDIR) + NO2(NDUV))
NO       6.0 PPM  NO2     7.0 PPM  NOX     13.0 PPM [ CHEMILUMINESCENCE  ]
EMISSIONS INDEX, LB/1000 LB FUEL: CO=  42.91                 CHX=  18.99
              CHEMILUMINESCENCE NOX=   1.91,   NDIR + NDUV NOX=   1.92

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .008922
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  96.5076 %
   CHECK ON F/A RATIO- F/A = .009117 W/O O2, CALCULATED O2 = 18.436 %

SMOKE INDEX: 2.49
SALTZMAN NOX = 10.2              PPM
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Figure 329. Final Prechamber Liner Modification "C" on Wall Fuel Film Injection at Nonregenerative 10% Power.

T63 COMBUSTOR EXPERIMENTS - RIG E/U 68, TEST SERIES 83, READING # 935
T3 FINAL PRECHAMBER MOD "C" - ON FILM NOZZLE # STD T63 INLET CONDITIONS
TEST DATE: 8-14-72 READING WAS TAKEN AT 1435:46 HOURS

CYCLE POINT 6 25 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.214	LB/SEC	AVG BURNER INLET TEMP	354.	DEG F
AVG BURNER INLET PRES	54.7	PSIA	AVG BURNER OUTLET TEMP	1195.	DEG F
AVG BURNER DELTA P	7.37	"HG	PRESSURE LOSS	6.62	%
OVERALL F/A RATIO	.01215	(F/M)	FUEL FLOW RATE	96.83	LB/HR
AIR LOAD FACTOR	1.1555		PATTERN FACTOR	.40167	
BOT HOT SPOT: # 16 = 1532.		DEG F	MAX BOT / AVG BOT	1.2826	
FUEL INLET TEMPERATURE	95.	DEG F	FUEL INLET PRESSURE	50.5	PSIA

HEAT LOADING PARAMETER .31614E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1478.	5	932.	15	1446.	19	1232.	24	1504.	27	1365.	36	1088.
ANNULUS 2	4	1338.	7	10[illegible]9.	16	1532.	21	1261.	25	1373.	34	1054.	37	1079.
ANNULUS 3	5	954.	14	1299.	17	1385.	22	1296.	26	1161.	35	988.	39	953.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE			RIGHT SIDE		
TOTAL PRESSURE	54.54	PSIA	TOTAL PRESSURE	54.67	PSIA
STATIC PRESSURE	54.39	PSIA	STATIC PRESSURE	54.41	PSIA
VELOCITY DELTA P	.50	"HG	VELOCITY DELTA P	.54	"HG
AIR TEMPERATURE	354.	DEG F	AIR TEMPERATURE	354.	DEG F
AIR VELOCITY	111.84	FT/SEC	AIR VELOCITY	116.54	FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) -.077 "HG

AIR FLOW DATA: P-REF= 104.2 PSIA DELTA P= 2.33 "HG T-REF= 106. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	358.	HZ	VOLUMETRIC FLOW RATE	15.65	GAL/HR
FUEL PRESSURE AT F/M	223.5	PSIA	FUEL TEMP AT F/M	94.	DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 51.84 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 53.94 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 7.33 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2	1.937 %	O2	18.000 %	CO	142.9 PPM	CHX	26.0 PPM
NO	4.2 PPM	NO2	9.7 PPM	NOX	13.9 PPM	(NO(NDIR) + NO2(NDUV))	
NO	6.6 PPM	NO2	8.9 PPM	NOX	15.6 PPM	(CHEMILUMINESCENCE)	

EMISSIONS INDEX, LB/1000 LB FUEL: CO= 11.51 CHX= 3.30
CHEMILUMINESCENCE NOX= 2.06, NDIR + NDUV NOX= 1.84

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .009248
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.2118 %
CHECK ON F/A RATIO- F/A = .009382 W/O O2, CALCULATED O2 = 18.292 %

SMOKE INDEX: .29
SALTZMAN NOX = 12.4 PPM

Figure 330. Final Prechamber Liner Modification "C" on Wall Fuel Film Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 68, TEST SERIES 83, READING #    936
T63 FINAL PRECHAMBER MOD "C" - ON FILM NOZZLE # STD T63 INLET CONDITIONS
TEST DATE:  8-14-72                     READING WAS TAKEN AT 1509135 HOURS

CYCLE POINT  5                                          40 % POWER SETTING

                   ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.575 LB/SEC     AVG BURNER INLET TEMP   397. DEG F
AVG BURNER INLET PRES  63.6    PSIA      AVG BURNER OUTLET TEMP 1317. DEG F
AVG BURNER DELTA P      9.30    "HG      PRESSURE LOSS               7.18 %
OVERALL F/A RATIO      .01334  (F/M)     FUEL FLOW RATE           123.65 LB/HR
AIR LOAD FACTOR        1.1844            PATTERN FACTOR           .36459
BOT HOT SPOTS  # 16 # 1653.  DEG F       MAX BOT / AVG BOT        1.2546
FUEL INLET TEMPERATURE  97.  DEG F       FUEL INLET PRESSURE        59.7  PSIA
HEAT LOADING PARAMETER  .34671E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1224.  6 1475. 15 1582. 19 1328. 24 1612. 27 1419. 36 1215.
ANNULUS 2  4 1229.  7 1076. 16 1653. 21 1363. 25 1489. 34 1200. 37 1184.
ANNULUS 3  5 1065. 14 1487. 17 1489. 22 1434. 26 1315. 35 1131. 39 1093.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          63.57   PSIA    TOTAL PRESSURE          63.70   PSIA
STATIC PRESSURE         63.16   PSIA    STATIC PRESSURE         63.30   PSIA
VELOCITY DELTA P         .34    "HG     VELOCITY DELTA P          .81    "HG
AIR TEMPERATURE         397.  DEG F     AIR TEMPERATURE          397.  DEG F
AIR VELOCITY          138.70 FT/SEC     AIR VELOCITY           136.11 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]        -.253    "HG

AIR FLOW DATA: P-REF= 103.4 PSIA   DELTA P= 3.19 "HG   T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       457.      HZ    VOLUMETRIC FLOW RATE  20.01 GAL/HR
FUEL PRESSURE AT F/M  213.6     PSIA    FUEL TEMP AT F/M          96.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   59.07 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            62.39 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               9.18  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   2.083 %     O2  18.400 %     CO    158.7 PPM     CHX    17.6 PPM
 NO     4.9 PPM  NO2     14.7 PPM  NOX    19.5 PPM [NO(NDIR) + NO2(NDUV)]
 NO    12.0 PPM  NO2     13.1 PPM  NOX    25.1 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.66                  CHX=   2.04
                 CHEMILUMINESCENCE NOX=   3.03,    NDIR + NDUV NOX=   2.36

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .009988
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.4981 %
   CHECK ON F/A RATIO- F/A = .010055 W/O O2, CALCULATED O2 = 18.086 %

SMOKE INDEX: 2.36
SALTZMAN NOX = 25.4              PPM
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Figure 331. Final Prechamber Liner Modification "C" on Wall Fuel Film Injection at Nonregenerative 40% Power.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 68, TEST SERIES 63, READING # 937
T63 FINAL PRECHAMBER MOD "C" - ON FILM NOZZLE * STD T63 INLET CONDITIONS
TEST DATE: 8-14-72 READING WAS TAKEN AT 1547:21 HOURS

CYCLE POINT 4 55 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.775	LB/SEC	AVG BURNER INLET TEMP	429.	DEG F
AVG BURNER INLET PRES	71.6	PSIA	AVG BURNER OUTLET TEMP	1418.	DEG F
AVG BURNER DELTA P	10.13	"HG	PRESSURE LOSS	5.95	%
OVERALL F/A RATIO	.01452	(F/P)	FUEL FLOW RATE	145.04	LB/HR
AIR LOAD FACTOR	1.1561		PATTERN FACTOR	.36351	
BOT HOT SPOT: # 24 =	1778.	DEG F	MAX BOT / AVG BOT	1.2535	
FUEL INLET TEMPERATURE	99.	DEG F	FUEL INLET PRESSURE	67.9	PSIA

HEAT LOADING PARAMETER .36157E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1318.	6	1139.	15	1689.	19	1416.	24	1778.	27	1589.	36	1291.
ANNULUS 2	4	1337.	7	1122.	16	1750.	21	1514.	25	1615.	34	1281.	37	1245.
ANNULUS 3	5	1134.	14	1566.	17	1605.	22	1581.	26	1426.	35	1217.	39	1173.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE				RIGHT SIDE	
TOTAL PRESSURE	71.55	PSIA	TOTAL PRESSURE	71.60	PSIA
STATIC PRESSURE	71.07	PSIA	STATIC PRESSURE	71.28	PSIA
VELOCITY DELTA P	.98	"HG	VELOCITY DELTA P	.65	"HG
AIR TEMPERATURE	429.	DEG F	AIR TEMPERATURE	429.	DEG F
AIR VELOCITY	143.94	FT/SEC	AIR VELOCITY	116.63	FT/SEC

DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.092 "HG

AIR FLOW DATA: P-REF= 102.6 PSIA DELTA P= 3.74 "HG T-REF= 105. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	537.	HZ	VOLUMETRIC FLOW RATE	23.50	GAL/HR
FUEL PRESSURE AT F/M	207.0	PSIA	FUEL TEMP AT F/M	99.	DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 66.60 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 70.50 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 10.08 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 2.254 % O2 17.800 % CO 160.7 PPM CHX 7.2 PPM
NO 12.7 PPM NO2 17.2 PPM NOX 29.8 PPM [NO(NDIR) + NO2(NDUV)]
NO 14.8 PPM NO2 25.4 PPM NOX 40.2 PPM [CHEMILUMINESCENCE]
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 10.86 CHX= .77
CHEMILUMINESCENCE NOX= 4.46, NDIR + NDUV NOX= 3.31

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .010887
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.5500 %
CHECK ON F/A RATIO- F/A = .010863 W/O O2, CALCULATED O2 = 17.847 %

SMOKE INDEX: .06
SALTZMAN NOX = 42.9 PPM

Figure 332. Final Prechamber Liner Modification "C" on Wall Fuel Film Injection at Nonregenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 68, TEST SERIES 83, READING #    938
T63 FINAL PRECHAMBER MOD "C" - ON FILM NOZZLE @ STD T63 INLET CONDITIONS
TEST DATE: 8-14-72                       READING WAS TAKEN AT 1608:10 HOURS

CYCLE POINT  3                                          75 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.996 LB/SEC     AVG BURNER INLET TEMP    472. DEG F
AVG BURNER INLET PRES   80.9    PSIA      AVG BURNER OUTLET TEMP 1500. DEG F
AVG BURNER DELTA P      10.91    "HG      PRESSURE LOSS            6.62 %
OVERALL F/A RATIO       .01664  (F/P)     FUEL FLOW RATE         179.50 LB/HR
AIR LOAD FACTOR         1.1301            PATTERN FACTOR         .43752
BOT HOT SPOT:  # 24 = 2065.  DEG F        MAX BOT / AVG BOT      1.3069
FUEL INLET TEMPERATURE 100.  DEG F        FUEL INLET PRESSURE     79.6   PSIA
HEAT LOADING PARAMETER  .39588E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1397.  6 1200. 15 1885. 19 1631. 24 2065. 27 1798. 36 1440.
ANNULUS 2   4 1402.  7 1164. 16 2001. 21 1741. 25 1836. 34 1378. 37 1376.
ANNULUS 3   5 1239. 14 1735. 17 1833. 22 1854. 26 1603. 35 1296. 39 1309.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          80.86    PSIA     TOTAL PRESSURE          80.95   PSIA
STATIC PRESSURE         80.44    PSIA     STATIC PRESSURE         80.60   PSIA
VELOCITY DELTA P          .85     "HG     VELOCITY DELTA P          .70    "HG
AIR TEMPERATURE          472.   DEG F     AIR TEMPERATURE          472.  DEG F
AIR VELOCITY          129.00 FT/SEC       AIR VELOCITY          117.09 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.178    "HG

AIR FLOW DATA: P-REF= 182.0 PSIA   DELTA P= 4.39 "HG   T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       667.      HZ     VOLUMETRIC FLOW RATE  29.11 GAL/HR
FUEL PRESSURE AT F/M   193.8     PSIA     FUEL TEMP AT F/M        100.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   75.55 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            79.28 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE              10.82  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2    2.580 %     O2  17.400 %     CO    170.0 PPM     CHX      1.3 PPM
 NO     30.9 PPM  NO2     18.2 PPM  NOX     49.1 PPM [NO(NDIR) + NO2(NDUV)]
 NO     26.5 PPM  NO2     21.4 PPM  NOX     48.0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.09                CHX=      .12
                 CHEMILUMINESCENCE NOX=  4.65,    NDIR + NDUV NOX=    4.77

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .012083
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6480 %
   CHECK ON F/A RATIO- F/A = .012025 W/O O2, CALCULATED O2 = 17.502 %

SMOKE INDEX: 0
SALTZMAN NOX = 58.1              PPM
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Figure 333. Final Prechamber Liner Modification "C" on Wall Fuel Film Injection at Nonregenerative 75% Power.

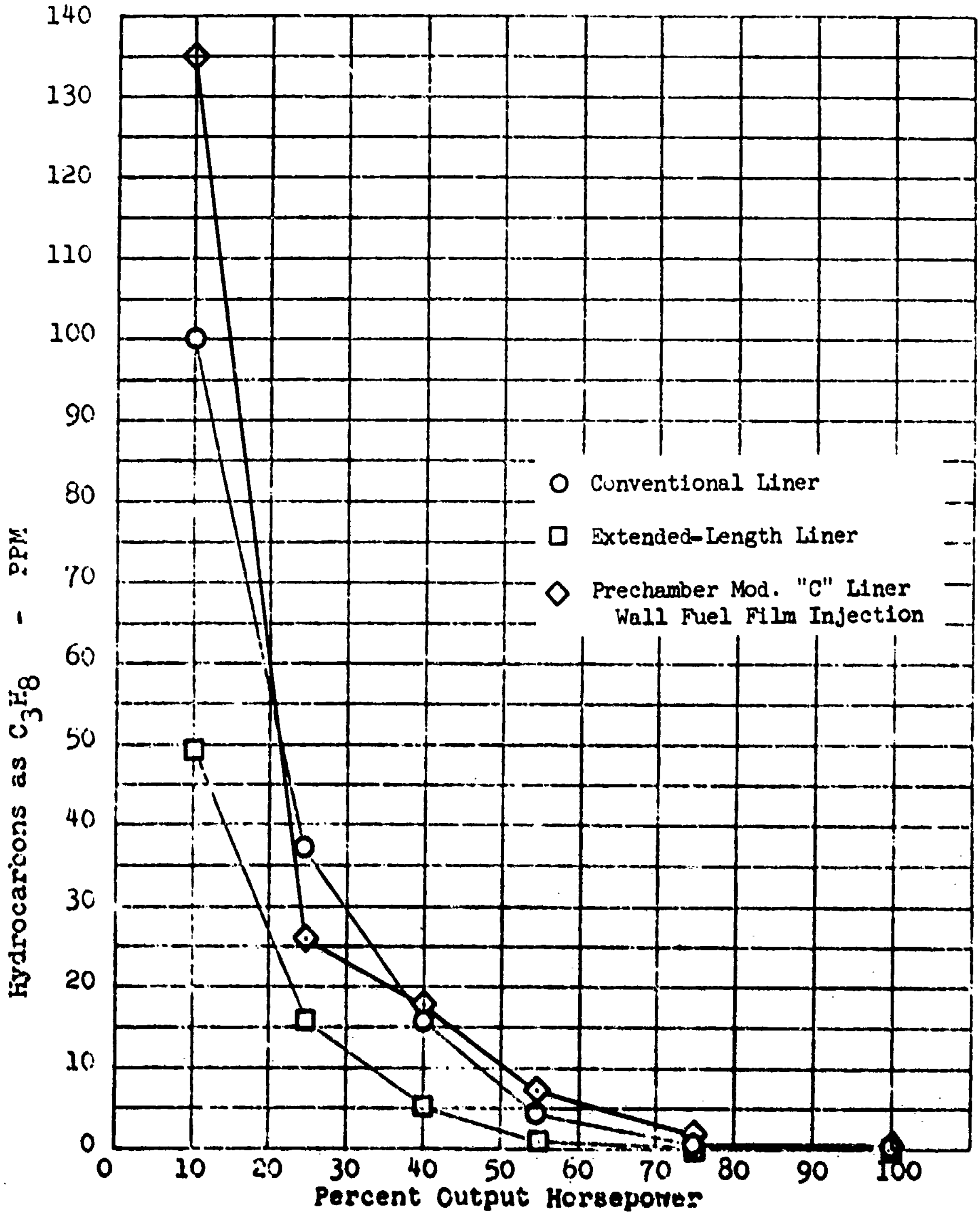

Figure 334. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Prechamber Final Design Modification "C" Combustor and T63 Baseline Combustors.

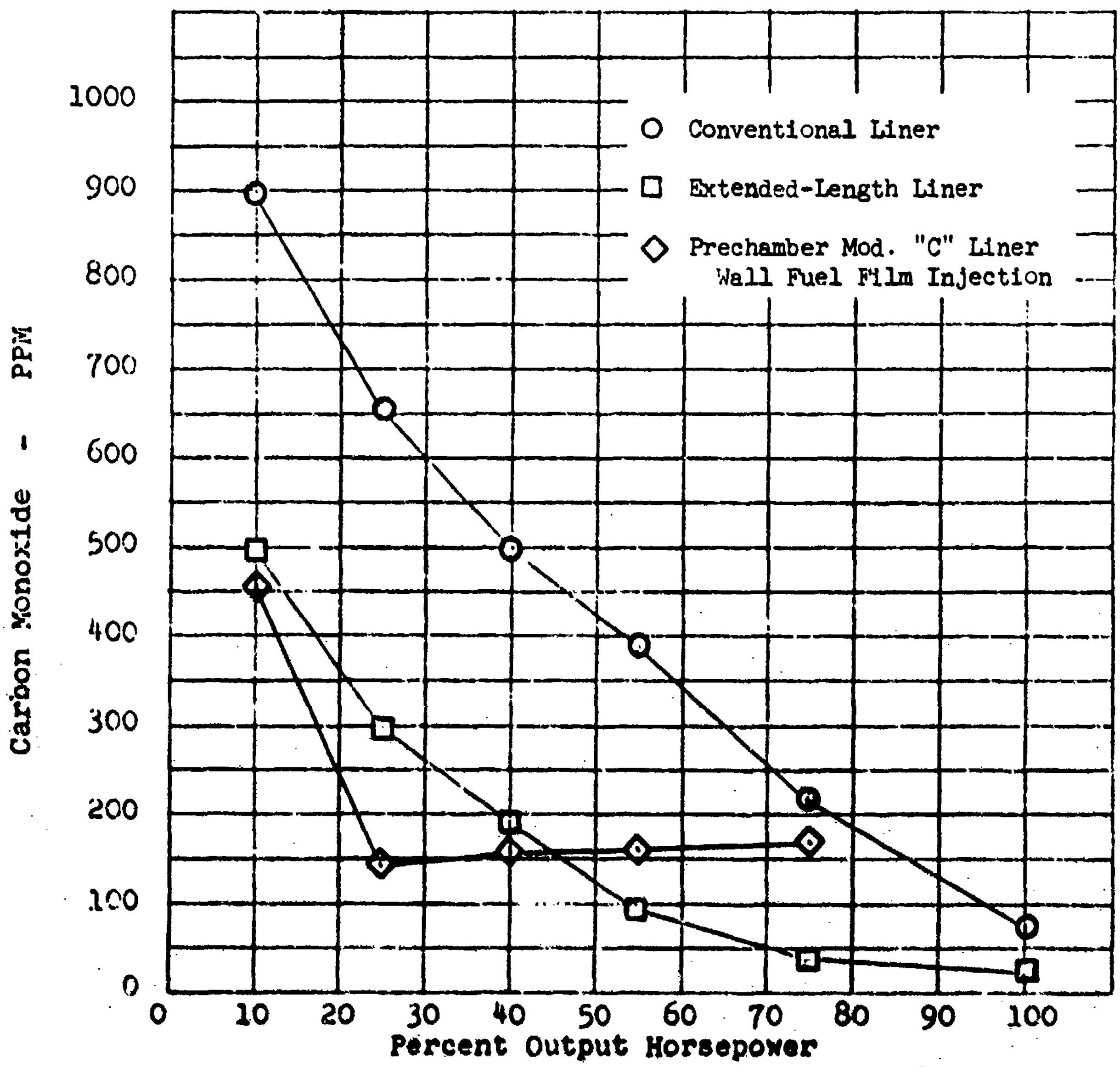

Figure 335. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Prechamber Final Design Modification "C" Combustor and T63 Baseline Combustors.

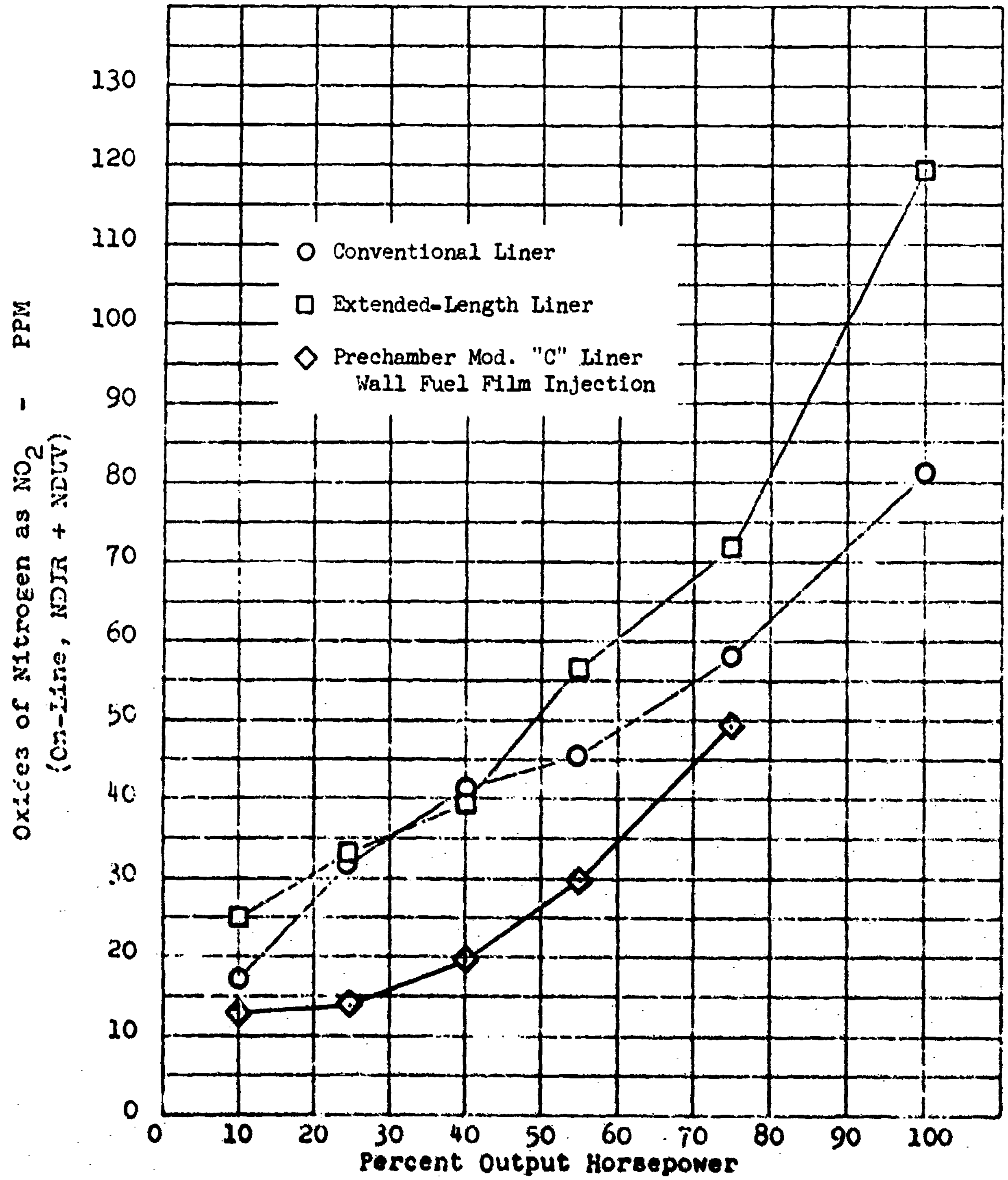

Figure 336. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber Final Design Modification "C" Combustor and T63 Baseline Combustors.

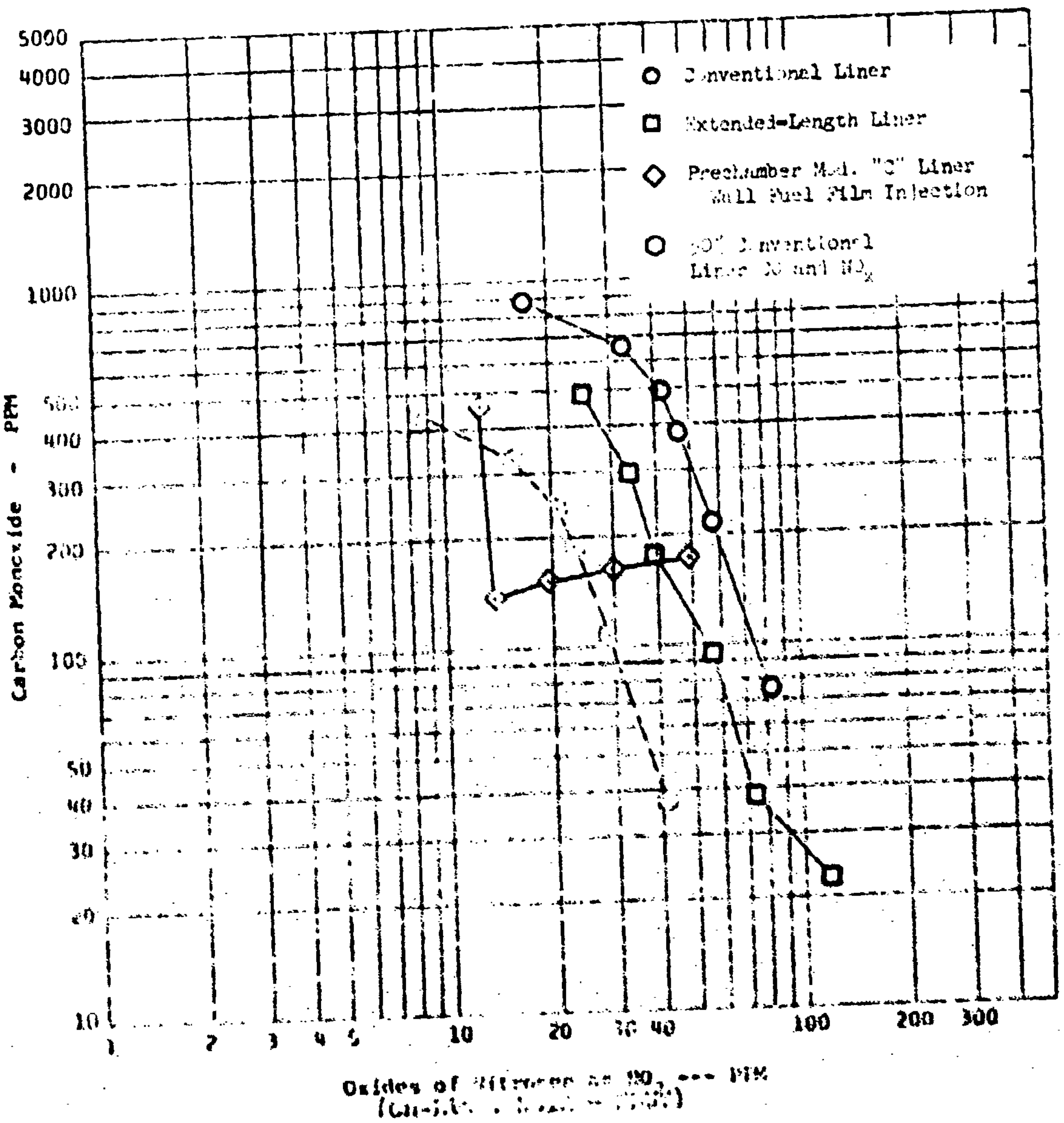

Figure 337. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Extended-Length, Prechamber Final Design Modification "C" Combustor and T63 Baseline Combustors.

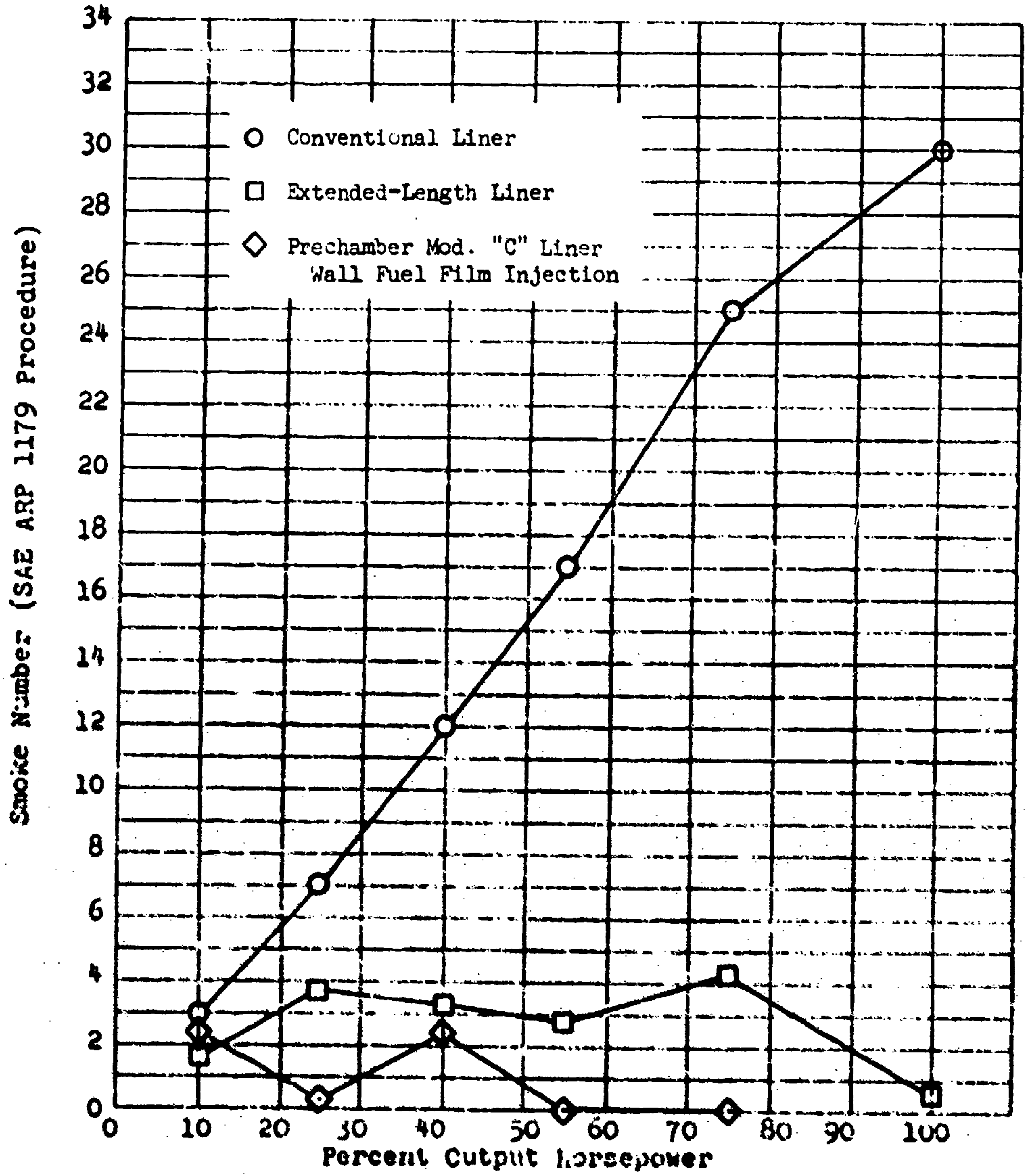

Figure 338. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Prechamber Final Design Modification "C" Combustor and T63 Baseline Combustors.

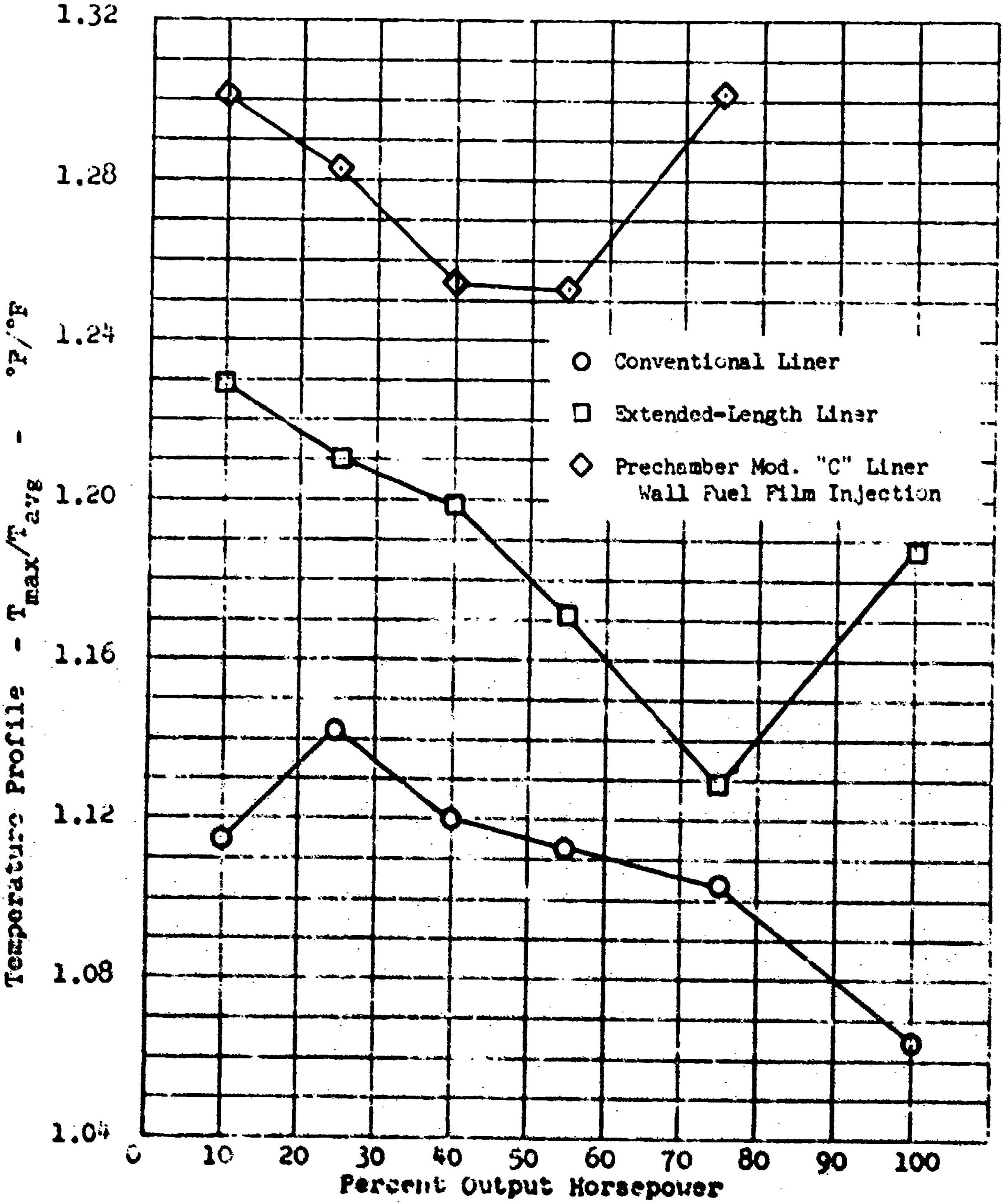

Figure 339. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Prechamber Final Design Modification "C" Combustor and T63 Baseline Combustors.

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T63 COMBUSTON EXPERIMENTS - RIG B/U 74, TEST SERIES 92, READING #   1821
   T63 FINAL PRECHAMBER - MOD "D" - RUN AT STD T63 INLET CONDITIONS,
TEST DATE:  8-28-72                      READING WAS TAKEN AT 1428:28 HOURS

CYCLE POINT  6                                         25 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2,286 LB/SEC    AVG BURNER INLET TEMP   352. DEG F
AVG BURNER INLET PRES  54,4    PSIA      AVG BURNER OUTLET TEMP 1142. DEG F
AVG BURNER DELTA P      7,44    "HG      PRESSURE LOSS            6,72 %
OVERALL F/A RATIO     ,01208  (F/M)      FUEL FLOW RATE          95,82 LB/HR
AIR LOAD FACTOR        1,1541            PATTERN FACTOR         ,42532
BOT HOT SPOT:  # 16 = 1478.  DEG F       MAX BOT / AVG BOT      1.2943
FUEL INLET TEMPERATURE  81.  DEG F       FUEL INLET PRESSURE      58,3  PSIA
HEAT LOADING PARAMETER  ,31448E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1071.  6  951. 15 1438. 19 1122, 24 1416, 27 1311. 36 1083.
ANNULUS 2   4 1135.  7  979. 16 1478. 21 1223. 25 1247. 34 1083. 37  974.
ANNULUS 3   5  911. 14 1265. 17 1268. 22 1213. 26  988. 35  899. 39  988.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          54,48    PSIA    TOTAL PRESSURE          54,49   PSIA
STATIC PRESSURE         54,05    PSIA    STATIC PRESSURE         54,27   PSIA
VELOCITY DELTA P          ,72    "HG     VELOCITY DELTA P          ,48    "HG
AIR TEMPERATURE          352.  DEG F     AIR TEMPERATURE          352.  DEG F
AIR VELOCITY           134,99 FT/SEC     AIR VELOCITY           108,81 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -,177    "HG

AIR FLOW DATA: P-REF= 104,7 PSIA    DELTA P= 2,38 "HG    T-REF= 103. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       384.      HZ    VOLUMETRIC FLOW RATE  18,47 GAL/HR
FUEL PRESSURE AT F/M  118,8     PSIA     FUEL TEMP AT F/M          81.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     50,79 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              53,82 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 7,38  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2,188 %      O2  18,088 %      CO   189,5 PPM     CHX     18,3 PPM
 NO      7,0 PPM   NO2     8,7 PPM   NOX    18,7 PPM (NO(NDIR) + NO2(NDUV))
 NO      8,7 PPM   NO2     3,4 PPM   NOX    18,1 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  18,03                   CHX=   1,01
                 CHEMILUMINESCENCE NOX=   2,48,    NDIR + NDUV NOX=    2,23

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         ,010414
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  88,3874 %
   CHECK ON F/A RATIO- F/A = ,010482 W/O O2, CALCULATED O2 = 17,883 %

SMOKE INDEX: .00
SALTZMAN NOX = 19.2              PPM              E.I. = 2.56
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Figure 340. Final Prechamber Liner Modification "D" on Wall Fuel Film Injection at Nonregenerative 10% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 74, TEST SERIES 92, READING #   1020
  T63 FINAL PRECHAMBER - MOD "D" - RUN AT STD T63 INLET CONDITIONS,
TEST DATE:  8-29-72                          READING WAS TAKEN AT 1400113 HOURS

CYCLE POINT  1                                              10 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW        1,045 LB/SEC     AVG BURNER INLET TEMP    301. DEG F
AVG BURNER INLET PRES  44,2    PSIA     AVG BURNER OUTLET TEMP 1026. DEG F
AVG BURNER DELTA P      5,52    "HG     PRESSURE LOSS             6.14 %
OVERALL F/A RATIO      .01099  (F/M)    FUEL FLOW RATE           73.03 LB/HR
AIR LOAD FACTOR        1.1524           PATTERN FACTOR          .51044
BOT HOT SPOT:  # 16 = 1397.  DEG F      MAX BOT / AVG BOT       1.3610
FUEL INLET TEMPERATURE  90.  DEG F      FUEL INLET PRESSURE       40.5  PSIA
HEAT LOADING PARAMETER  .29516E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  925.   6  895. 15 1360. 19 1023. 24 1000. 27 1006. 36 1147.
ANNULUS 2   4 1009.   7  939. 16 1397. 21  978. 25  963. 34  900. 37 1142.
ANNULUS 3   5  800.  14 1144. 17 1231. 22  836. 26  847. 35  902. 39  854.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          44.14    PSIA    TOTAL PRESSURE          44.17    PSIA
STATIC PRESSURE         43.86    PSIA    STATIC PRESSURE         43.88    PSIA
VELOCITY DELTA P          .58     "HG    VELOCITY DELTA P          .59     "HG
AIR TEMPERATURE          300.   DEG F    AIR TEMPERATURE          301.   DEG F
AIR VELOCITY           129.71 FT/SEC     AIR VELOCITY           130.90 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.030     "HG

AIR FLOW DATA: P-REF= 104.7 PSIA   DELTA P= 1.60 "HG    T-REF= 102. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      270.       HZ    VOLUMETRIC FLOW RATE  11.77 GAL/HR
FUEL PRESSURE AT F/M  120.7     PSIA     FUEL TEMP AT F/M            89.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    41.44 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                43.83 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   5.40  "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    2.030 %     O2  18.200 %      CO    420.0 PPM     CHX     85.0 PPM
 NO      7.0 PPM  NO2      9.7 PPM  NOX     16.7 PPM (NO(NDIR) + NO2(NDUV))
 NO      5.2 PPM  NO2      8.3 PPM  NOX     13.5 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  37.95                    CHX=  11.00
                  CHEMILUMINESCENCE NOX=   1.90,    NDIR + NDUV NOX=   2.45

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010129
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  97.7201 %
   CHECK ON F/A RATIO- F/A = .010176 W/O O2, CALCULATED O2 = 18.180 %

SMOKE INDEX: .01
SALTZMAN NOX = 12.4                  PPM               E.T.: 1.82
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Figure 341. Final Prechamber Liner Modification "D" on Wall Fuel Film Injection at Nonregenerative 25% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 74, TEST SERIES 92, READING #   1022
   T63 FINAL PRECHAMBER - MOD "D" - RUN AT STD T63 INLET CONDITIONS.
TEST DATE: 8-28-72                          READING WAS TAKEN AT 1453:43 HOURS

CYCLE POINT  5                                             40 % POWER SETTING

                    ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW           2.557 LB/SEC    AVG BURNER INLET TEMP    396. DEG F
AVG BURNER INLET PRES  64.3    PSIA      AVG BURNER OUTLET TEMP 1254. DEG F
AVG BURNER DELTA P      8.88    "HG       PRESSURE LOSS              6.78 %
OVERALL F/A RATIO     .01305   (F/M)     FUEL FLOW RATE           120.15 LB/HR
AIR LOAD FACTOR        1.1632            PATTERN FACTOR            .33691
BOT HOT SPOT: # 16 = 1543.  DEG F       MAX BOT / AVG BOT         1.2305
FUEL INLET TEMPERATURE  92.  DEG F       FUEL INLET PRESSURE        60.4  PSIA
HEAT LOADING PARAMETER  .33341E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1208.  6 1054. 15 1535. 19 1201. 24 1541. 27 1415. 36 1203.
ANNULUS 2   4 1279.  7 1065. 16 1543. 21 1327. 25 1389. 34 1154. 37 1094.
ANNULUS 3   5 1030. 14 1372. 17 1357. 22 1320. 26 1132. 35 1055. 39 1061.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          64.27    PSIA    TOTAL PRESSURE          64.34    PSIA
STATIC PRESSURE         64.03    PSIA    STATIC PRESSURE         64.04    PSIA
VELOCITY DELTA P          .49     "HG    VELOCITY DELTA P          .61     "HG
AIR TEMPERATURE          396.   DEG F    AIR TEMPERATURE          396.   DEG F
AIR VELOCITY           105.33 FT/SEC    AIR VELOCITY           117.48 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]        -.143     "HG

AIR FLOW DATA: P-REF= 103.6 PSIA   DELTA P= 3.12 "HG   T-REF= 103. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       443.      HZ    VOLUMETRIC FLOW RATE  19.39 GAL/HR
FUEL PRESSURE AT F/M  112.5    PSIA     FUEL TEMP AT F/M           92.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     59.94 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                63.29 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   8.81  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.229 %     O2  17.700 %     CO    129.4 PPM     CHX      4.4 PPM
 NO     14.8 PPM  NO2     10.6 PPM  NOX     25.4 PPM [NO(NDIR) + NO2(NDUV)]
 NO     17.3 PPM  NO2     10.2 PPM  NOX     27.5 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   9.71                 CHX=     .52
                  CHEMILUMINESCENCE NOX=   3.39,    NDIR + NDUV NOX=    3.13

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .016822
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6534 %
   CHECK ON F/A RATIO- F/A = .018728 W/O O2, CALCULATED O2 = 17.885 %

SMOKE INDEX: .00
SALTZMAN NOX = 32.6                PPM              E.I. = 4.02
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Figure 342. Final Prechamber Liner Modification "D" on Wall Fuel Film Injection at Nonregenerative 40% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 74, TEST SERIES 92, READING #   1823
   T63 FINAL PRECHAMBER - MOD "D" - RUN AT STD T63 INLET CONDITIONS.
TEST DATE: 6-28-72                          READING WAS TAKEN AT 1528:43 HOURS

CYCLE POINT  4                                           55 % POWER SETTING

                  ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW        2.748 LB/SEC     AVG BURNER INLET TEMP     438. DEG F
AVG BURNER INLET PRES  71.4    PSIA     AVG BURNER OUTLET TEMP 1381. DEG F
AVG BURNER DELTA P     9.78     "HG     PRESSURE LOSS             6.67 %
OVERALL F/A RATIO     .01468  (F/M)     FUEL FLOW RATE          144.47 LB/HR
AIR LOAD FACTOR       1.1476            PATTERN FACTOR          .33454
BOT HOT SPOT: # 16 = 1699.  DEG F       MAX BOT / AVG BOT       1.2384
FUEL INLET TEMPERATURE  93.  DEG F      FUEL INLET PRESSURE      67.9   PSIA
HEAT LOADING PARAMETER  .36889E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1342.  6 1154. 13 1673. 19 1388. 24 1687. 27 1589. 36 1332.
ANNULUS 2   4 1485.  7 1173. 16 1699. 21 1458. 25 1511. 34 1235. 37 1232.
ANNULUS 3   5 1158. 14 1522. 17 1514. 22 1457. 26 1285. 35 1164. 39 1198.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE           71.45    PSIA   TOTAL PRESSURE          71.42   PSIA
STATIC PRESSURE          71.86    PSIA   STATIC PRESSURE         71.81   PSIA
VELOCITY DELTA P          .79      "HG   VELOCITY DELTA P          .82    "HG
AIR TEMPERATURE          438.   DEG F    AIR TEMPERATURE          438.  DEG F
AIR VELOCITY           129.18 FT/SEC     AIR VELOCITY           131.31 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]            .063   "HG

AIR FLOW DATA: P-REF= 182.8 PSIA    DELTA P= 3.63 "HG    T-REF= 181. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      533.      HZ     VOLUMETRIC FLOW RATE  23.33 GAL/HR
FUEL PRESSURE AT F/M   181.4    PSIA     FUEL TEMP AT F/M        93.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     66.67 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                  70.21 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                     9.73  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    2.476 %    O2  17.408 %    CO    155.7 PPM    CHX      .7 PPM
 NO     25.3 PPM  NO2    14.7 PPM  NOX    40.0 PPM [NO(NDIR) + NO2(NDUV)]
 NO     27.5 PPM  NO2    11.7 PPM  NOX    39.2 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO= 10.53                  CHX=    .07
                  CHEMILUMINESCENCE NOX=   4.33,   NDIR + NDUV NOX=   4.41

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011978
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6799 %
   CHECK ON F/A RATIO- F/A = .011988 W/O O2, CALCULATED O2 = 17.539 %

SMOKE INDEX: .00
SALTZMAN NOX = 38.2              PPM              E.I. = 4.21
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Figure 343. Final Prechamber Liner Modification "D" on Wall Fuel Film Injection at Nonregenerative 55% Power.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 74, TEST SERIES 92, READING #   1024
   T63 FINAL PRECHAMBER - MOD "D" - RUN AT STD T63 INLET CONDITIONS.
TEST DATE: 8-28-72                        READING WAS TAKEN AT 1541:27 HOURS

CYCLE POINT  3                                          75 % POWER SETTING

                     ***** EXPERIMENTAL  CONDITIONS *****
BURNER AIR FLOW          2.955 LB/SEC    AVG BURNER INLET TEMP    472. DEG F
AVG BURNER INLET PRES   81.4    PSIA     AVG BURNER OUTLET TEMP 1551. DEG F
AVG BURNER DELTA P     10.28    "HG      PRESSURE LOSS            6.15 %
OVERALL F/A RATIO      .01656  (F/M)     FUEL FLOW RATE         176.20 LB/HR
AIR LOAD FACTOR        1.1079            PATTERN FACTOR          .45571
BOT HOT SPOT:  # 16 = 2043.   DEG F      MAX BOT / AVG BOT       1.3170
FUEL INLET TEMPERATURE  93.   DEG F      FUEL INLET PRESSURE      79.2  PSIA
HEAT LOADING PARAMETER  .38613E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
              ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1488.  6 1385. 15 1976. 19 1488. 24 1789. 27 1465. 36 1671.
ANNULUS 2   4 1462.  7 1337. 16 2043. 21 1495. 25 1455. 34 1612. 37 1534.
ANNULUS 3   5 1271. 14 1844. 17 1775. 22 1484. 26 1311. 35 1495. 39 1358.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           81.35    PSIA   TOTAL PRESSURE           81.50   PSIA
STATIC PRESSURE          31.07    PSIA   STATIC PRESSURE          81.01   PSIA
VELOCITY DELTA P          .59     "HG    VELOCITY DELTA P          .99     "HG
AIR TEMPERATURE          472.   DEG F    AIR TEMPERATURE          472.   DEG F
AIR VELOCITY           106.62 FT/SEC     AIR VELOCITY           138.61 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.290    "HG

AIR FLOW DATA: P-REF= 102.4 PSIA   DELTA P= 4.22 "HG    T-REF= 101. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       852.      HZ    VOLUMETRIC FLOW RATE  28.46 GAL/HR
FUEL PRESSURE AT F/M   114.4    PSIA     FUEL TEMP AT F/M          94.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE      76.42 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               80.04 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 10.05  "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    3.034 %     O2  16.600 %      CO    156.7 PPM      CHX       .2 PPM
 NO     40.8 PPM  NO2    16.6 PPM  NOX     57.4 PPM [NO(NDIR) + NO2(NDUV)]
 NO     39.2 PPM  NO2    11.7 PPM  NOX     50.9 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    9.30                CHX=     .02
                    CHEMILUMINESCENCE NOX=    4.96,    NDIR + NDUV NOX=   5.66

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .014524
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7346 %
   CHECK ON F/A RATIO- F/A = .014336 W/O O2, CALCULATED O2 = 16.803 %

SMOKE INDEX: .00
SALTZMAN NOX = 66.5               PPM                 E.I. = 6.49
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Figure 344. Final Prechamber Liner Modification "D" on Wall Fuel Film Injection at Nonregenerative 75% Power.

The vaporizer tube centerbody in the Prechamber Modification "D" combustor permitted a significant reduction in hydrocarbons. As can be seen in Figure 345, the C_xH_y concentrations from the Prechamber combustor are all lower than those from the conventional liner. Carbon monoxide emissions were reduced slightly more in Modification "D", Figure 346, but the NO_x concentrations seen in Figure 347 definitely increased over the Modification "C" emission concentrations. The CO vs NO_x curve for the Prechamber Modification "D", Figure 348, is quite similar to the previous configuration.

Smoke/particulates from Modification "D" were zero. This is the only configuration of a "Final Prechamber Combustor" that produced no smoke. Temperature profile, however, remained a significant problem, see Figure 350. In no Final Prechamber configuration did wall fuel film operation produce an exhaust profile comparable to pressure atomizer operation or to the "Preliminary Prechamber Combustor", which used wall fuel film injection.

Using extrapolated 100% power emission concentrations when no test data were available, the Final Prechamber Modification "D" combustor was seen to prodice 47% less total emissions than the conventional T63-A-5A combustor over the LOH duty cycle and allowed no increase in any constituent emission. Even though this combustor fell 3% short of the 50% emission reduction goal, its elimination of smoke and reduction of each constituent emission make it the "best" wall fuel film Prechamber combustor of the Final Prechamber configurations.

A summary of five Final Prechamber combustors operated on wall fuel film is presented in Table LXXXII. It is clear that the rich operation of the Initial Design and Modification "A" produced low hydrocarbon and carbon monoxide but high smoke. Modifications "B", "C", and "D", however, produced almost no smoke, with their more lean reaction zone and vaporizer section, but suffered from increased hydrocarbons and carbon monoxide.

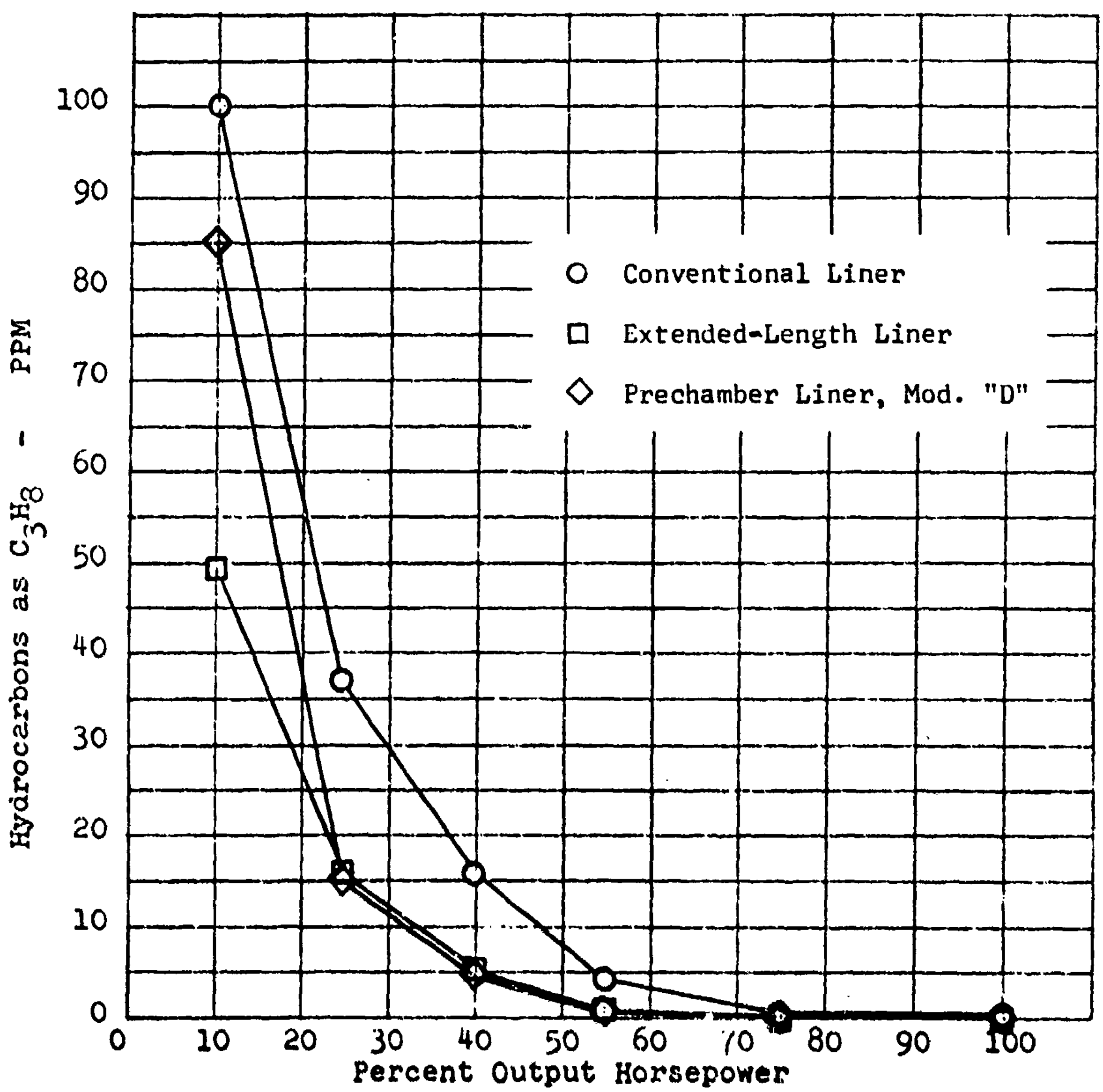

Figure 345. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Extended-Length, Final-Design, Prechamber Combustor Modification "D" Operating on Wall Fuel Film Injection and Baseline T63 Combustors.

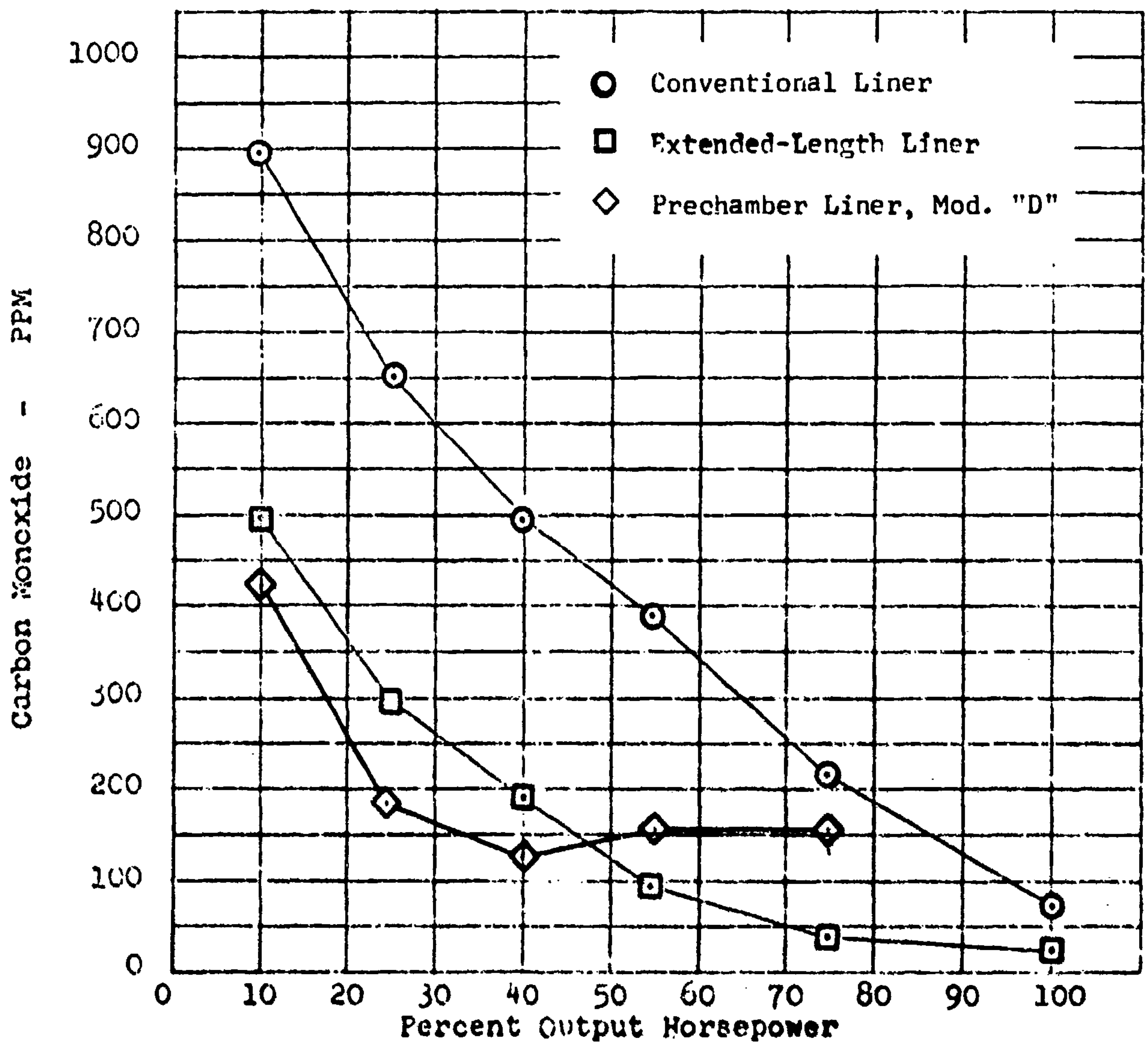

Figure 346. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Extended-Length, Final Design, Prechamber Combustor Modification "D" Operating on Wall Fuel Film Injection and Baseline T63 Combustors.

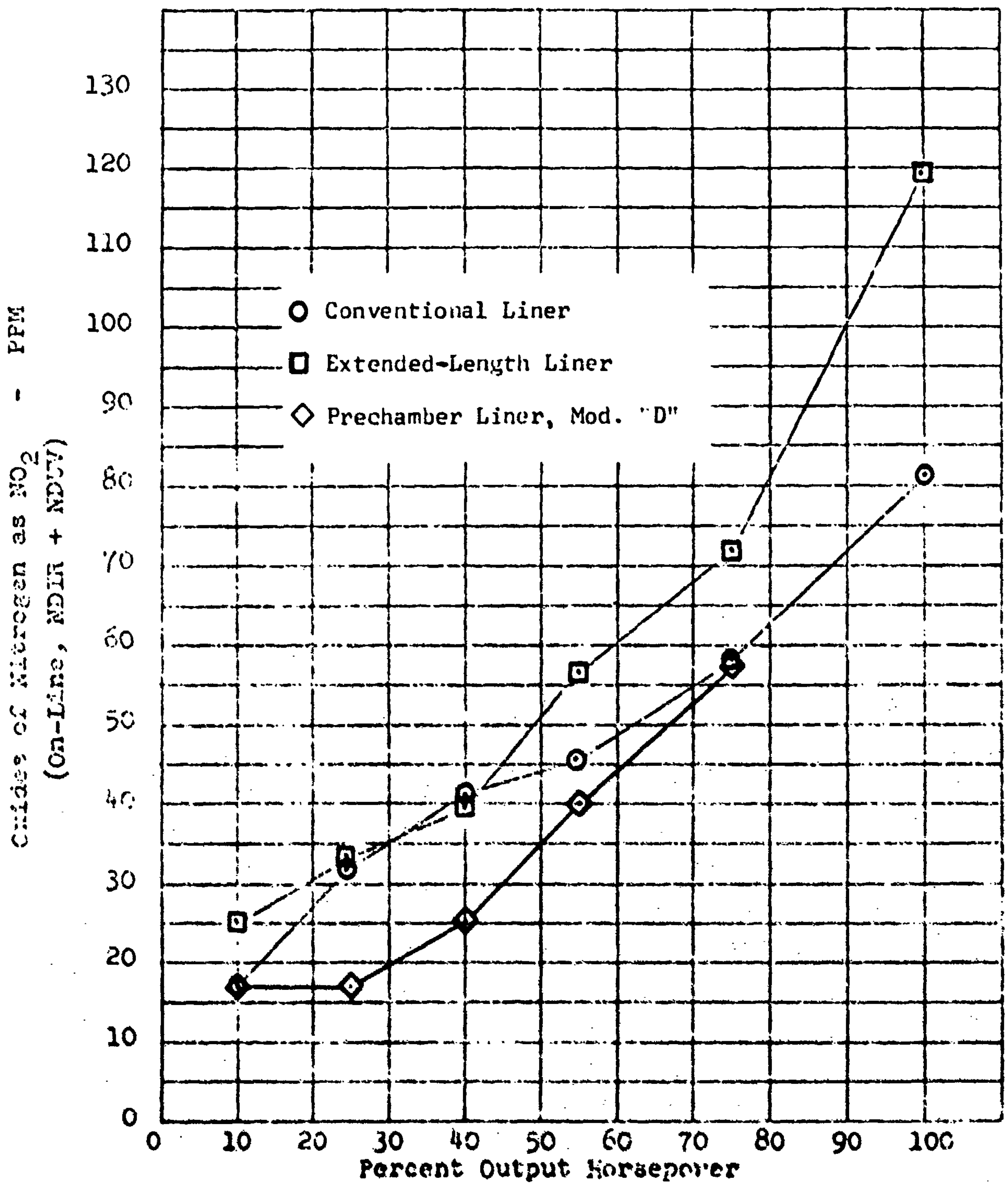

Figure 347. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Extended-Length, Final-Design, Prechamber Combustor Modification "D" Operating on Wall Fuel Film Injection and Baseline T63 Combustors.

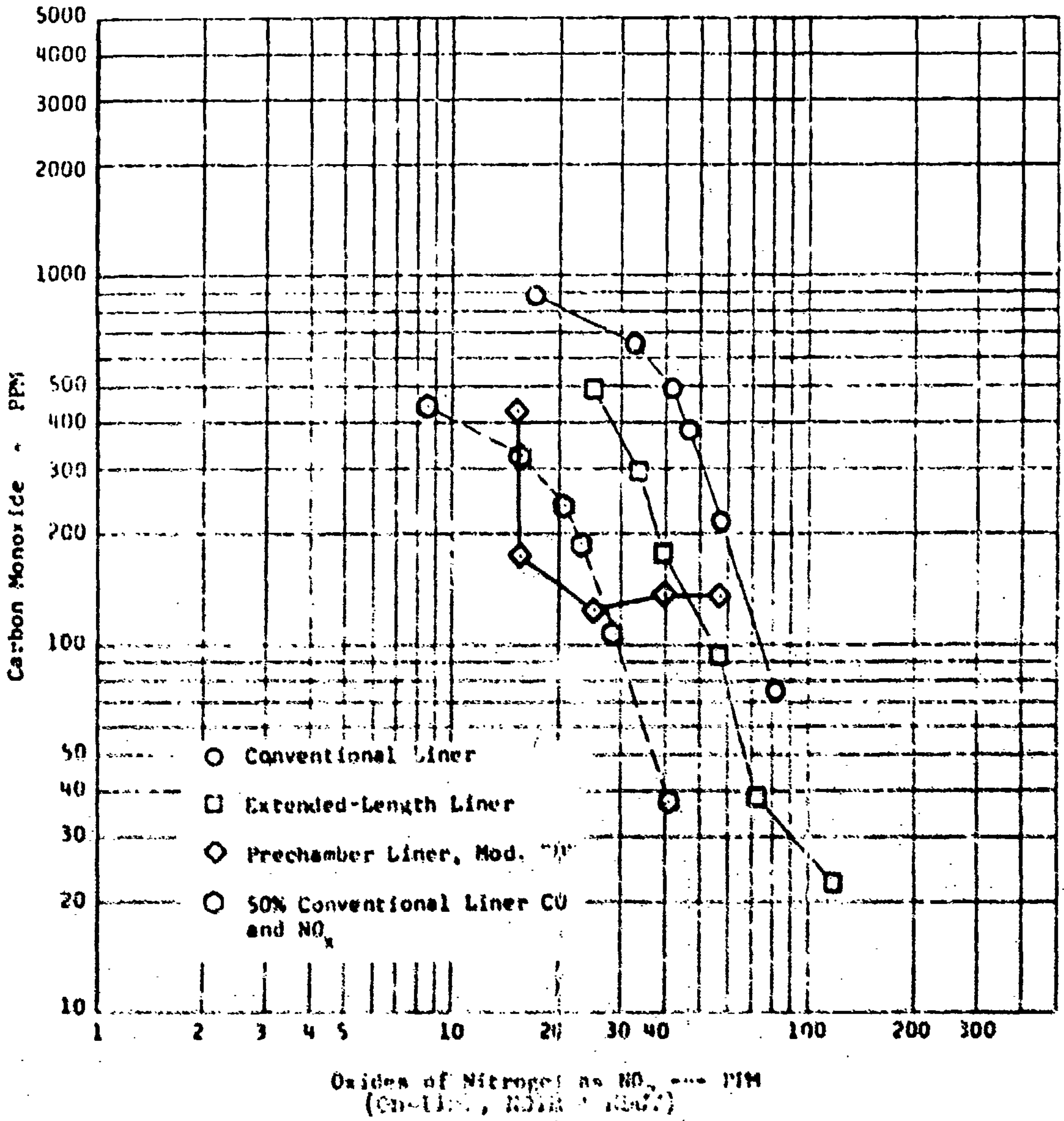

Figure 348. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Extended-Length, Final-Design, Prechamber Combustor Modification "D" Operating on Wall Fuel Film Injection and Baseline T63 Combustors.

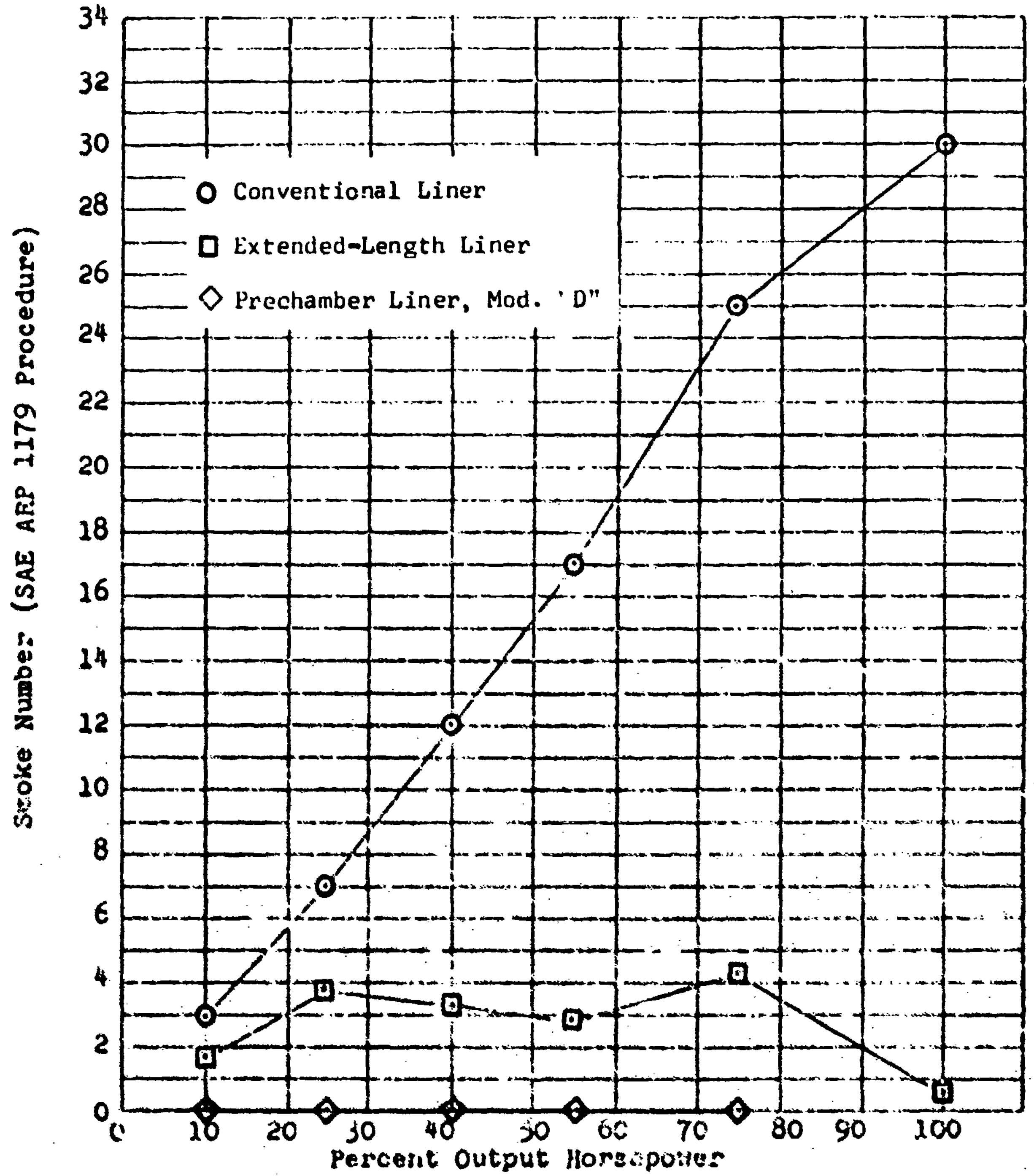

Figure 349. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Extended-Length, Final-Design, Prechamber Combustor Modification "D" Operating on Wall Fuel Film Injection and Baseline T63 Combustors.

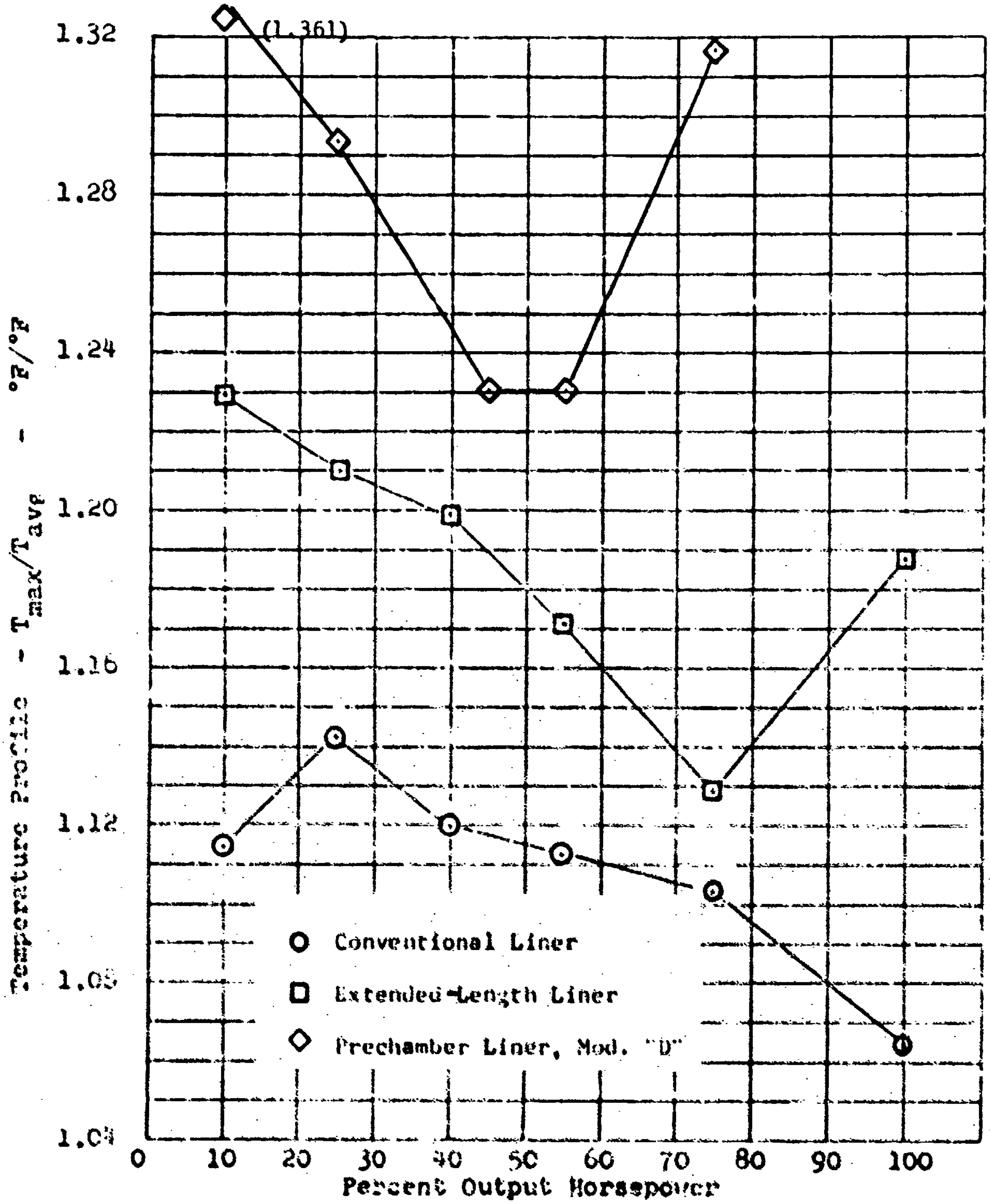

Figure 350. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Extended-Length, Final-Design, Prechamber Combustor Modification "D" Operating on Wall Fuel Film Injection and Baseline T63 Combustors.

TABLE LXXXII. EMISSION INDEX SUMMARY FOR T63 BASELINE AND FINAL PRECHAMBER COMBUSTORS

Combustor Tested	C_xH_y	CO	NO_x	Particulates	Total Emissions
EMISSION INDEX (lb/1000 lb fuel)					
• Baseline	1.544	26.094	5.068	.239	32.945
• Final Prechamber-Wall Fuel Film					
Initial	.126	13.247	4.732	.337	18.442
Mod. "A"	.176	10.910	4.378	.274	15.738
Mod. "B"	2.077	13.810	4.092	.022	20.001
Mod. "C"	2.119	12.834	3.670	.007	18.630
Mod. "D"	1.033	11.947	4.584	.000	17.564
RELATIVE EMISSION INDEX (%)					
• Baseline	100	100	100	100	100
• Final Prechamber-Wall Fuel Film					
Initial	8	51	93	141	56
Mod. "A"	11		86	115	48
Mod. "B"	135	53	81	9	61
Mod. "C"	137	49	72	3	57
Mod. "D"	67	46	90	0	53

APPENDIX IV
DESIGN AND EXPERIMENTAL RESULTS OF THE FINAL, MODIFIED CONVENTIONAL LOW-EMISSION COMBUSTORS

Two final combustor configurations were selected from the test results of the seventeen preliminary combustors evaluated during the first part of Task 3. These two final combustors were identified as the "Final Prechamber Combustor Liner" and the "Final Modified Conventional Combustor Liner". Reported in this appendix is the "Final Modified Conventional Combustor Liner".

DESIGN

Four preliminary low-emission combustor concepts which demonstrated effective emission reductions were incorporated into the "Final Modified Conventional Combustor Liner". The Modified Conventional Combustor concept was envisioned as the inclusion of current-technology emission abatement techniques into the basic envelope of the Conventional T63-A-5A combustor liner. The axial length of the Modified Conventional combustor was maintained equal to the conventional combustor, as were the liner dome, ignition system, primary zone section, and axial cross sections. The emission abatement concepts added to the conventional combustor were the following:

- Convection cooling of the primary zone.
- Delayed dilution.
- Variable dilution geometry.
- Air-blast fuel injection.

The first three of these concepts when incorporated into the Conventional T63-A-5A combustor liner resulted in the initial design Modified Conventional combustor liner shown in Figure 351. In this design, the variable-geometry dilution band was fabricated for two geometry settings. The "closed" setting was a set of six 1.047-inch-diameter holes which distributed the liner flow splits in the same proportion as the flow splits in the Conventional T63 combustor. In this setting, the maximum-power primary-zone equivalence ratio was 0.77, and the emission reductions obtained relied upon the primary-zone convection cooling and the delayed dilution. The second dilution geometry setting injected dilution air through a set of 1.37-inch-square holes. This setting repeated the flow splits in the regenerative T63 combustor and was intended for use at regenerative conditions.

The "Modified Conventional Initial Design Combustor" produced low total emissions, but NO_x and particulates were above the Conventional T63 levels. The initial design was reworked into Modification "A"

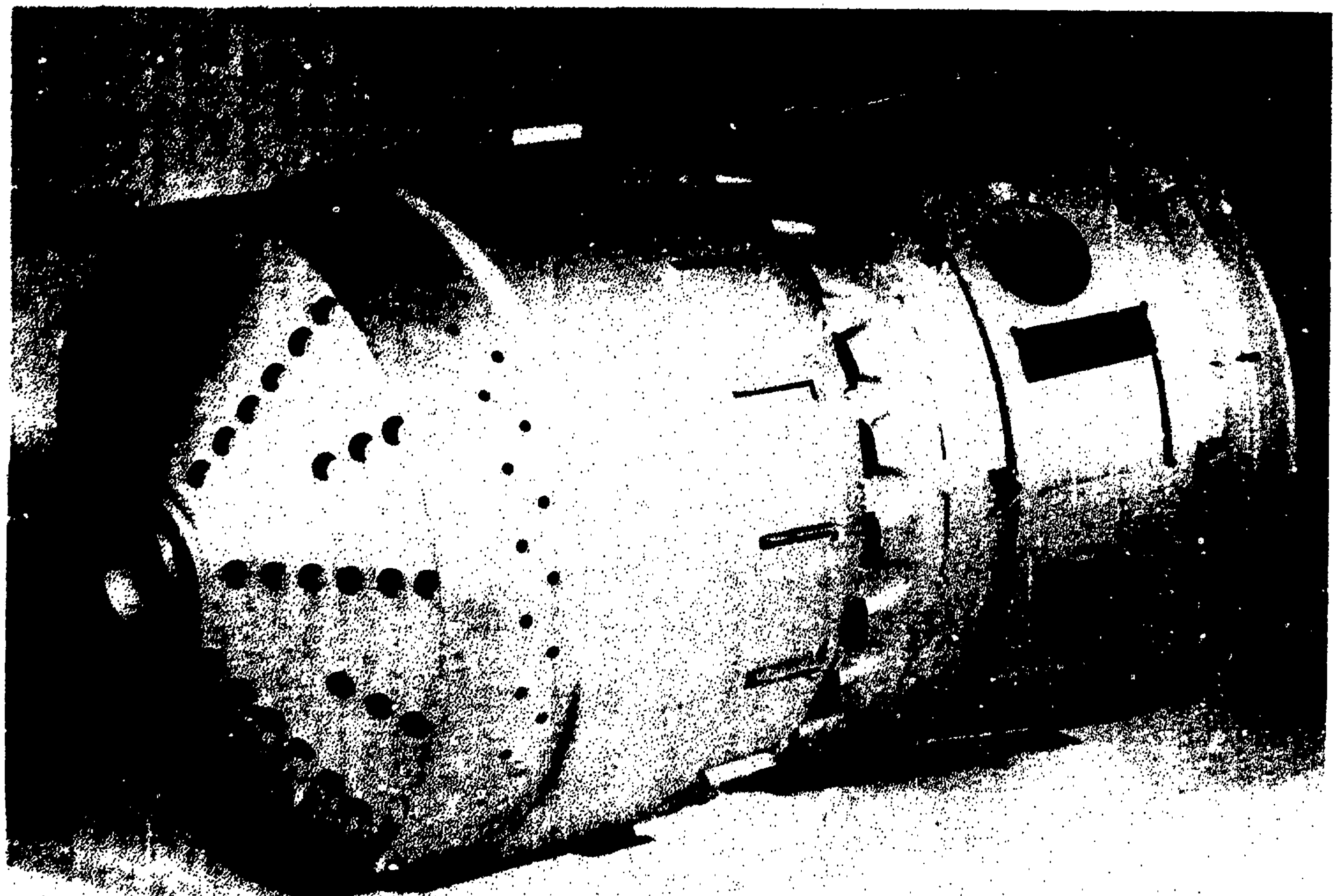

Figure 351. Final Low-Emission Modified Conventional Combustor Liner, Initial Design.

in an attempt to reduce the NO_x and particulates. The single change that was made was a rework of the dilution-zone variable-geometry section. First the dilution holes were moved 2.00 inches upstream from their initial axial location (2.10 inches from the end of the liner) to the location of the Conventional T63 combustor dilution holes (4.10 inches from the end of the liner). This location still retained some delayed dilution, as the trim air in the Conventional Liner, which is injected through a row of holes located an additional 1.25 inches upstream of the dilution holes, was combined with the dilution air at the dilution hole axial location. The dilution holes were redesigned into a set of six 1.22-inch-square holes with 0.41-inch-radius rounded corners. A photograph of the Modified Conventional Modification "A" combustor is shown in Figure 352.

A lack of variable-geometry effectiveness, which was experienced during the testing of the Modification "A" combustor, was found to have resulted from the seizing of the dilution slip band and then the severe bending of the variable-geometry actuator tabs. The deformation of the actuator tabs can be seen in Figure 352. The emission results were greatly increased over those from the initial design, since a reduction in total emissions of only 26% was realized. The poor performance was due in part to the low pressure loss and the insufficient mixing and recirculation resulting from this low loss.

Modification "B" of the "Final Modified Conventional Combustor Liner" was the refining of the concepts in Modification "A" plus the change from a standard T63 pressure atomizing fuel injector to an air-blast pressure atomizing fuel injector, which had been evaluated in the preliminary low-emission combustor concept tests. In addition to the fuel injector change, the dilution variable-geometry section was replaced with new hardware which improved the mechanical operation of the slip band and strengthened the actuator tabs. To increase the pressure loss and improve mixing and recirculation, the primary zone and dilution zone holes were reduced. The primary zone holes were reduced from 0.610 inch diameter to 0.500 inch diameter, and the dilution holes were reduced from six 1.22-inch-square holes with 0.41-inch-radius corners to four 1.22-inch by 1.41-inch holes with 0.41-inch-radius corners. The four dilution holes were fabricated on a basis of six holes; each pair of holes was adjacent to the inlet air from the two engine feed arms. An external view of the Modified Conventional Modification "B" combustor liner is presented in Figure 353 and an internal view in Figure 354.

The mechanical operation of the Modification "B" variable-geometry dilution slip band proved to be quite satisfactory, and four different geometry settings were used during the rig testing: 0%, 28%, 50%, and 71% closed. The 28% closed setting corresponded to the "nonregenerative" setting, duplicating the Conventional T63 combustor flow splits. The 0% closed setting corresponded to the "regenerative" liner flow splits.

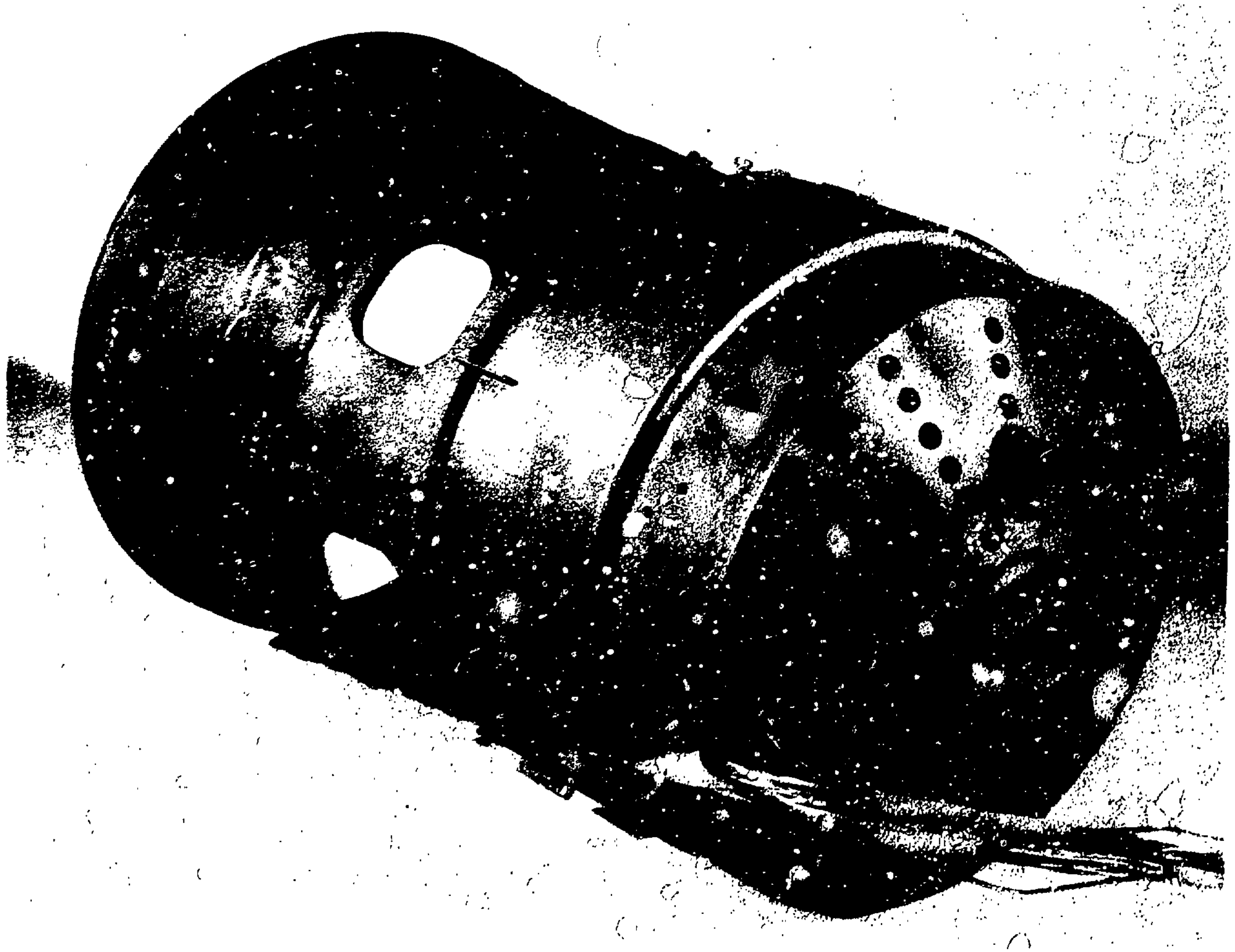

Figure 352. Final Low-Emission Modified Conventional Combustor Liner, Modification "A".

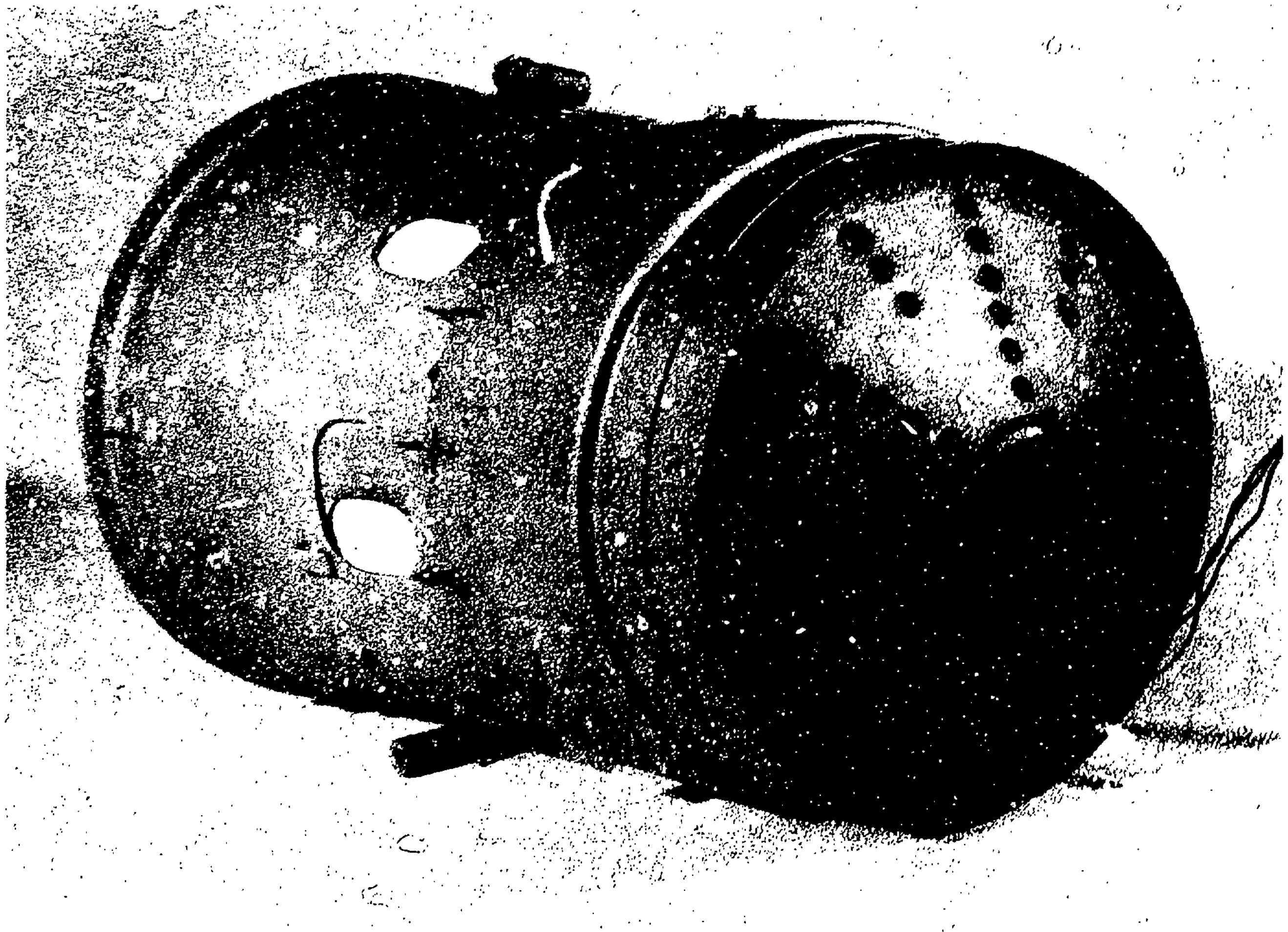

Figure 353. Final Low-Emission Modified Conventional Combustor Liner, Modification "B" - External View.

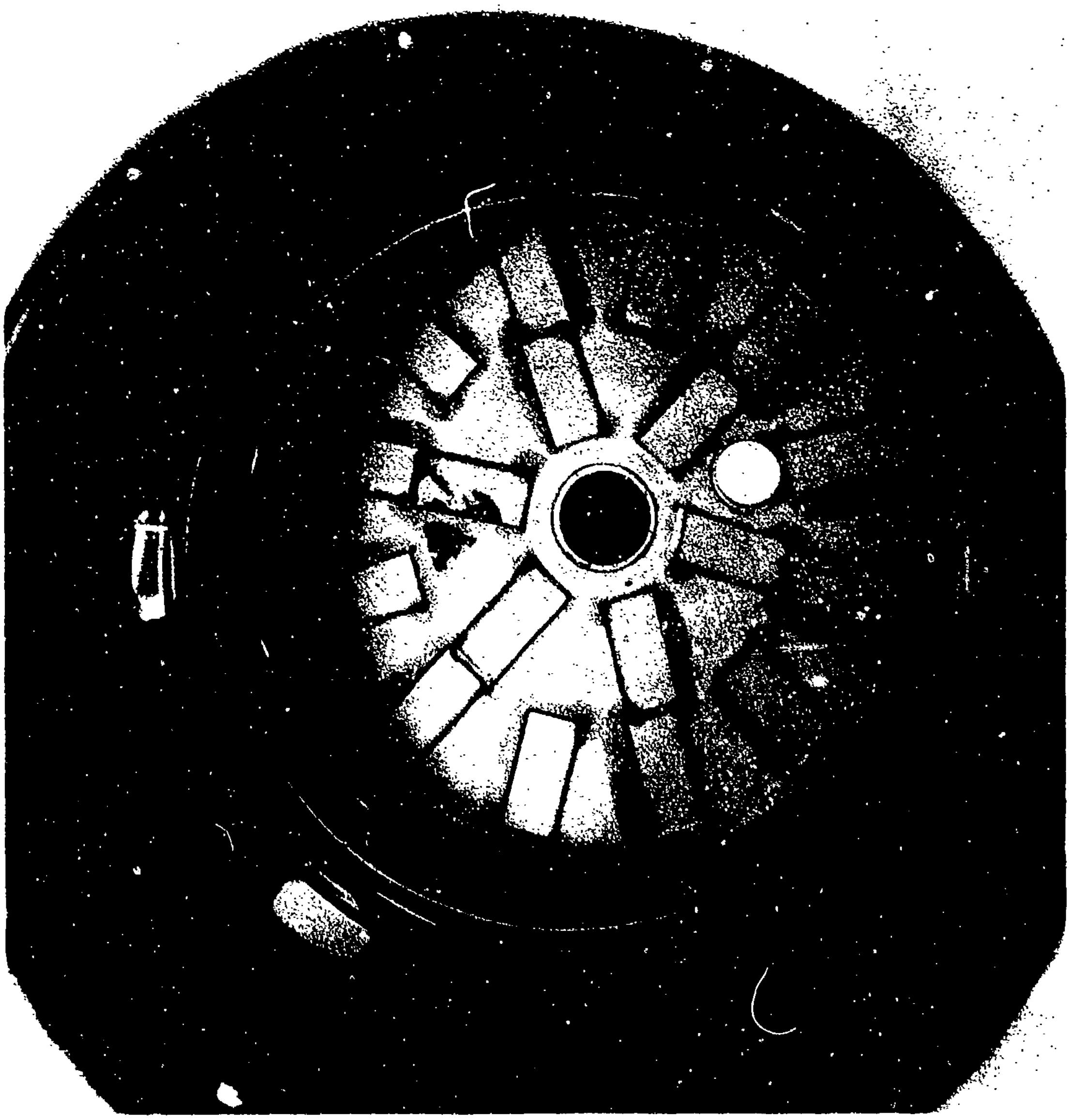

Figure 354. Final Low-Emission Modified Conventional Combustor Liner, Modification "B" - Internal View.

Modification "B" was the final configuration in the "Final Modified Conventional Combustor Liner" series on this contract. With two dilution geometry settings, 28% closed at low power conditions and 50% closed at the high power conditions, Modification "B" reduced total emissions 51% over the LOH duty cycle when compared to the Conventional T63-A-5A combustor emissions. All constituent emissions were reduced except particulates, which were 25% above the Conventional T63 baseline levels. Compared to the particulates measured from a Conventional T63 combustor in the second baseline retest, the Modified Conventional Modification "B" combustor particulates were 73% lower.

The detailed emissions and combustor performance results for the Modified Conventional combustors are presented in the next section of this appendix.

TEST RESULTS

The testing procedure followed for the final combustor configurations is shown in the schematic in Figure 355. The two final configurations, Modified Conventional and Prechamber, were fabricated and instrumented with skin thermocouples. Each was tested at T63 nonregenerative conditions and lean blowout was determined. After the data were analyzed and the duty cycle emission index values were computed, the liners were either modified and the nonregenerative tests rerun or the final modifications were tested at T63 regenerative conditions, ambient startup conditions, and a set of parametric conditions. The final set of tests was performed on Modification "B" of both final design configurations.

Emissions and combustor performance data for all three modifications of the Final Modified Conventional combustor liner were recorded at various dilution geometry settings and each of the six T63 nonregenerative operating conditions. In addition to the automatic data acquisition instrumentation read for each low-emission combustor tested, a set of three skin thermocouples was attached to the Modified Conventional combustors as indicated in Figure 356. Temperatures from these thermocouples were manually recorded at each data point for the initial design and Modification "A". Mechanical failure of the thermocouple leads inside the convection cooling shell prevented the acquisition of any skin temperatures from the Modification "B" testing.

The following sections present the test results from the Final Modified Conventional combustor tests.

Initial Design

The Final Modified Conventional Initial Design combustor liner incorporated two dilution geometry settings. The "open" setting was a set of six 1.37-inch-square holes, which enriched the primary

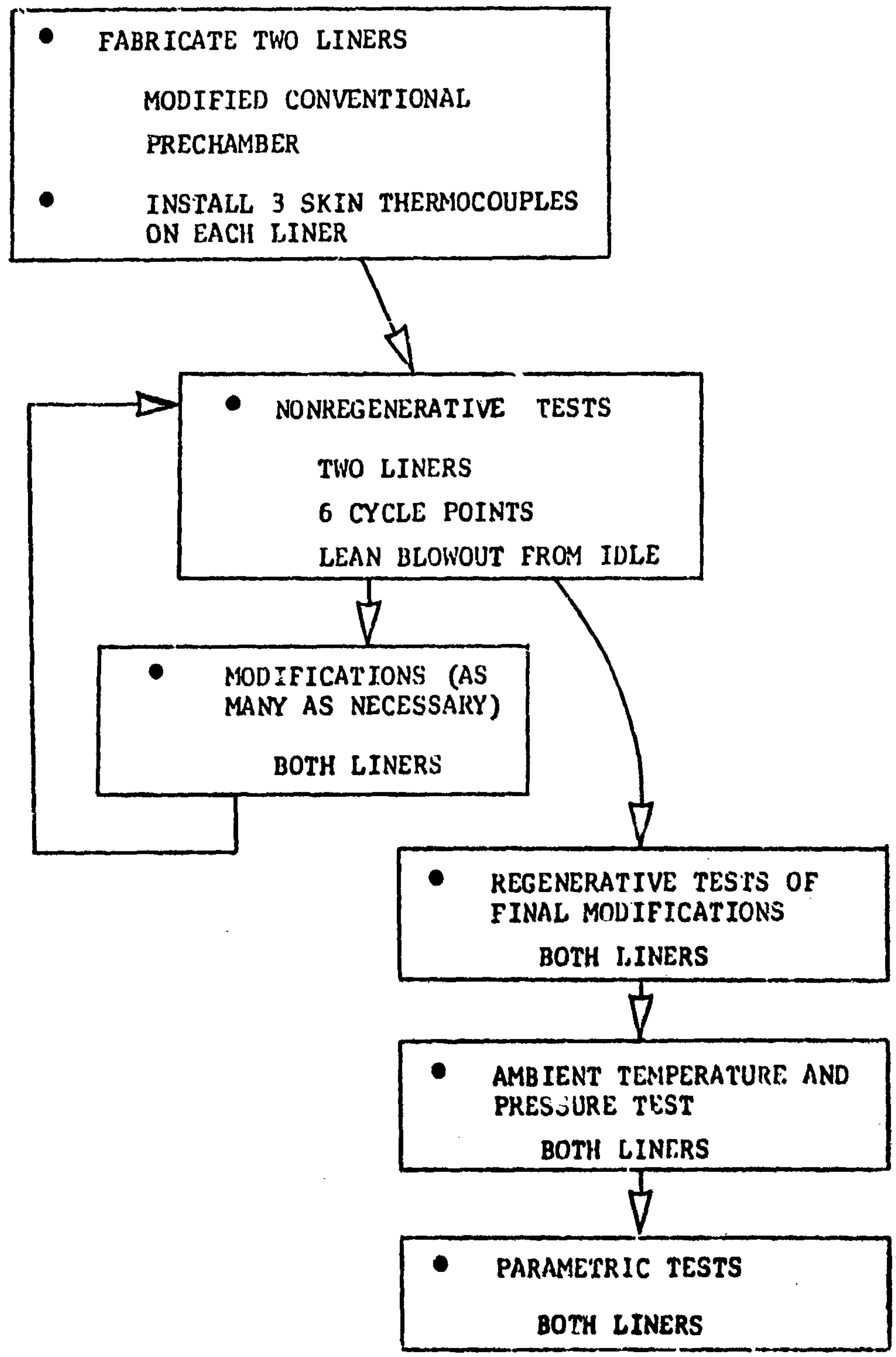

Figure 355. Program Plan for Testing Final Combustors.

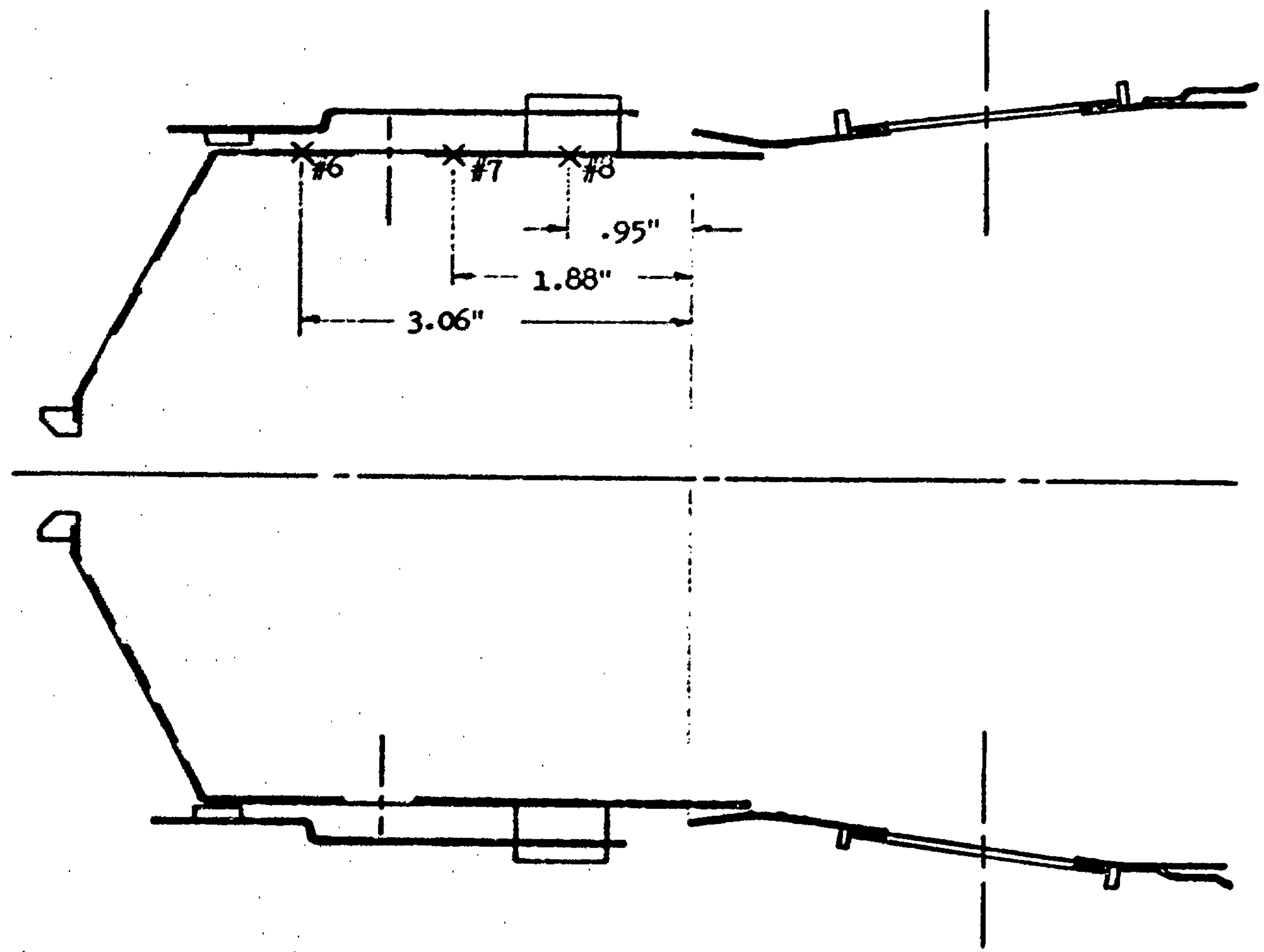

Figure 356. Final Design Modified Conventional Combustor Skin Thermocouple Locations.

zone to stoichiometric conditions at the nonregenerative fuel-air ratio at maximum power. This open setting was intended as the regenerative operating condition setting for the combustor. The closed setting was obtained by moving the dilution slip band until dilution air was injected through the set of six 1.047-inch diameter holes. This closed setting was intended as the nonregenerative operating condition setting for the combustor. During the non-regenerative tests, data were taken for both dilution settings for power settings up through 55% power. Only closed setting data were recorded for the 75% and 100% conditions because of the very poor exhaust temperature profile produced with the open dilution setting.

The detailed combustor/test rig data sheets from the "Final Modified Conventional Initial Design Combustor Liner" nonregenerative tests are presented in Figures 357 through 366. A summary of the emission, pressure-loss, and temperature-profile data is listed in Table LXXXIII for both dilution geometry settings of the Modified Conventional combustor. Pressure losses for the closed setting of the Modified Conventional liner compare quite favorably with the Conventional T63 liner pressure loss values.

The constituent emissions for the nonregenerative test of the Modified Conventional combustor liner are compared with the Conventional T63 combustor liner and the Preliminary Low-Emission Extended-Length Concept combustor liner in Figures 367 through 371. Both dilution geometry settings of the Modified Conventional combustor reduced the hydrocarbon emissions to a very low level, as can be seen in Figure 367. These emissions were even significantly below the Extended-Length liner concentrations. The carbon monoxide emissions, from the Modified Conventional combustor liner, Figure 368, were also reduced to a very low level, especially in the dilution closed position. Total nitrogen oxides for the Modified Conventional combustor were higher than for the Conventional T63 combustor, especially at the higher power settings, see Figure 369. The NO_x concentrations closely paralleled the levels produced by the Extended-Length liner. The CO vs NO_x tradeoff curves in Figure 370 clearly show the reductions in CO, but the success in these reductions was offset by the NO_x increases. Smoke/particulates for the Modified Conventional combustor were also higher than for the Conventional T63 combustor smoke levels, see Figure 371. The open dilution setting generated very high smoke, even at the low power settings.

When emission index values for the LOH duty cycle were computed using the emission constituent concentrations from the Modified Conventional combustor operating in the closed dilution setting, the results showed a reduction in total emissions of 59%, compared to the Conventional T63 combustor. This total emission reduction was accomplished because carbon monoxide mass emissions were reduced

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 46, TEST SERIES 55, READING #    722
T3 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE:  6-22-72                    READING WAS TAKEN AT 1442:56 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY   0 % CLOSED      10 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.892 LB/SEC    AVG BURNER INLET TEMP   301. DEG F
AVG BURNER INLET PRES   44.5   PSIA      AVG BURNER OUTLET TEMP  999. DEG F
AVG BURNER DELTA P       3.37   "HG      PRESSURE LOSS            3.72 %
OVERALL F/A RATIO       .01086  (F/P)    FUEL FLOW RATE          74.00 LB/HR
AIR LOAD FACTOR         1.1729           PATTERN FACTOR          .02139
BOT HOT SPOT:  # 21 = 1432.  DEG F       MAX BOT / AVG BOT       1.4339
FUEL INLET TEMPERATURE  98.   DEG F      FUEL INLET PRESSURE     198.4  PSIA
HEAT LOADING PARAMETER  .3604DE+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1107.   6  839. 15  882. 19 1127. 24  821. 27  841. 36 1052.
ANNULUS 2   4  925.   7  835. 16  952. 21 1432. 25  744. 34 1028. 37 1009.
ANNULUS 3   5  811.  14  981. 17  921. 22 1221. 26  751. 35 1117. 39 1306.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          44.40   PSIA    TOTAL PRESSURE         44.81   PSIA
STATIC PRESSURE         44.22   PSIA    STATIC PRESSURE        44.28   PSIA
VELOCITY DELTA P         .54    "HG     VELOCITY DELTA P        .47    "HG
AIR TEMPERATURE         301.  DEG F     AIR TEMPERATURE        302.  DEG F
AIR VELOCITY           124.97 FT/SEC    AIR VELOCITY          117.02 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.060    "HG

AIR FLOW DATA: P-UP= 105.4 PSIA   DELTA P= 1.61 "HG   T-REF= 81. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY     272.      HZ     VOLUMETRIC FLOW RATE  11.05 GAL/HR
FUEL PRESSURE AT F/M  274.6    PSIA     FUEL TEMP AT F/M        80.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    42.84 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             43.30 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                3.34  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   1.901 %     O2  18.700 %     CO   223.4 PPM     CHX     8.8 PPM
 NO    18.7 PPM  NO2    14.2 PPM  NOX    20.5 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM  NO2      .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  20.09                  CHX=    .92
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    3.07

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .009309
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.3906 %
   CHECK ON F/A RATIO- F/A = .009507 W/O O2, CALCULATED O2 = 18.240 %

SMOKE INDEX: 29.07
SALTZMAN NOX = 29.2                PPM  E.I.= 4.31
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Figure 357. Final Modified Conventional Liner, Initial Design, at Nonregenerative 10% Power - Open Setting.

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T63 COMBUSTOR EXPERIMENTS - RIG P/U 46, TEST SERIES 55, READING #    723
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72                     READING WAS TAKEN AT 15H21:58 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY 100 % CLOSED       10 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.893 LB/SEC    AVG BURNER INLET TEMP    300. DEG F
AVG BURNER INLET PRESS  44.3    PSIA     AVG BURNER OUTLET TEMP   998. DEG F
AVG BURNER DELTA P       4.50    "HG     PRESSURE LOSS             4.99 %
OVERALL F/A RATIO       .01085  (F/M)    FUEL FLOW RATE           73.92 LB/HR
AIR LOAD FACTOR         1.1773           PATTERN FACTOR           .22376
BOT HOT SPOT: # 21 = 1155.  DEG F        MAX BOT / AVG BOT        1.1566
FUEL INLET TEMPERATURE 105.  DEG F       FUEL INLET PRESSURE      199.6  PSIA
HEAT LOADING PARAMETER  .35162E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1000.  6  925. 15  920. 19 1053. 24  940. 27 1022. 36  982.
ANNULUS 2    4  889.  7  963. 16  967. 21 1155. 25  946. 34 1134. 37  970.
ANNULUS 3    5  973. 14  985. 17 1017. 22 1139. 26  970. 35 1082. 39 1044.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           44.31   PSIA    TOTAL PRESSURE         44.31   PSIA
STATIC PRESSURE          44.08   PSIA    STATIC PRESSURE        44.07   PSIA
VELOCITY DELTA P          .47    "HG     VELOCITY DELTA P         .51    "HG
AIR TEMPERATURE          300.  DEG F     AIR TEMPERATURE        300.  DEG F
AIR VELOCITY            117.34 FT/SEC    AIR VELOCITY          121.20 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.009    "HG

AIR FLOW DATA: PUPSTR= 145.5 PSIA    DELTA P= 1.61 "HG    T-REF=  82. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       272.     HZ     VOLUMETRIC FLOW RATE  11.06 GAL/HR
FUEL PRESSURE AT F/M    274.3    PSIA    FUEL TEMP AT F/M        82.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE      42.10 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               43.01 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  4.50  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.107 %      O2  18.500 %      CO    250.0 PPM     CHX    10.0 PPM
NO    10.0 PPM   NO2    12.0 PPM   NOX     23.4 PPM (NO(NDIR) + NO2(NDUV))
NO      .0 PPM   NO2      .0 PPM   NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  22.50                   CHX=   1.42
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    3.40

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010000
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.2000 %
   CHECK ON F/A RATIO- F/A = .010210 W/O O2, CALCULATED O2 = 18.045 %

SMOKE INDEX: 1.34
SALTZMAN NOX = 23.1            PPM     E.I. = 3.42
**************************************************************************
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Figure 358. Final Modified Conventional Liner, Initial Design, at Nonregenerative 10% Power - Closed Setting.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 46, TEST SERIES 55, READING #    724
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72                          READING WAS TAKEN AT 152614Z HOURS

CYCLE POINT  6    VARIABLE GEOMETRY 100 % CLOSED       25 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.256 LB/SEC   AVG BURNER INLET TEMP   355. DEG F
AVG BURNER INLET PRES   55.0   PSIA     AVG BURNER OUTLET TEMP 1120. DEG F
AVG BURNER DELTA P       5.45    "HG    PRESSURE LOSS              4.86 %
OVERALL F/A RATIO       .01200  (F/F)   FUEL FLOW RATE            97.46 LB/HR
AIR LOAD FACTOR         1.1701          PATTERN FACTOR           .25843
HOT HOT SPOT:  # 21 = 1329.  DEG F      MAX BOT / AVG BOT        1.1772
FUEL INLET TEMPERATURE 109.  DEG F      FUEL INLET PRESSURE      220.2  PSIA
HEAT LOADING PARAMETER  .38380E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1122.  6 1076. 15 1035. 19 1193. 24 1046. 27 1135. 36 1074.
ANNULUS 2   4 1070.  7 1118. 16 1067. 21 1329. 25 1059. 34 1202. 37 1090.
ANNULUS 3   5 1021. 14 1103. 17 1145. 22 1297. 26 1095. 35 1217. 30 1107.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          55.03   PSIA    TOTAL PRESSURE          55.04   PSIA
STATIC PRESSURE         54.73   PSIA    STATIC PRESSURE         54.70   PSIA
VELOCITY DELTA P          .62    "HG    VELOCITY DELTA P          .63    "HG
AIR TEMPERATURE         355.  DEG F     AIR TEMPERATURE         358.  DEG F
AIR VELOCITY           124.72 FT/SEC    AIR VELOCITY           115.12 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.007    "HG

AIR FLOW DATA: P-REF= 104.8 PSIA   DELTA P= 2.31 "HG   T-REF=  81. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      358.     HZ     VOLUMETRIC FLOW RATE  15.68 GAL/HR
FUEL PRESSURE AT F/M  344.9    PSIA     FUEL TEMP AT F/M          84.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   52.36 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            53.51 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               5.44  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   2.352 %      O2  18.000 %      CO    152.0 PPM     CHX      2.8 PPM
 NO    14.8 PPM  NO2      9.7 PPM  NOX      24.5 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM  NO2       .0 PPM  NOX        .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12.30               CHX=      .32
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   3.20

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011160
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.4800 %
   CHECK ON F/A RATIO- F/A = .011316 W/O O2, CALCULATED O2 = 17.712 %

SMOKE INDEX: 5.86
SALTZMAN NOX = 33.0                PPM    E.I. = 4.55
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Figure 359. Final Modified Conventional Liner, Initial Design, at Nonregenerative 25% Power - Closed Setting.

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T63 COMBUSTOR EXPERIMENTS - RIG S/U 46, TEST SERIES 55, READING #    728
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72                       READING WAS TAKEN AT 1543:11 HOURS

CYCLE POINT  6    VARIABLE GEOMETRY    0 % CLOSED       25 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         2.255 LB/SEC     AVG BURNER INLET TEMP    352. DEG F
AVG BURNER INLET PRES  54.9    PSIA      AVG BURNER OUTLET TEMP 1111. DEG F
AVG BURNER DELTA P      4.11    "HG      PRESSURE LOSS             3.67 %
OVERALL F/A RATIO       .01207  (F/P)    FUEL FLOW RATE           97.04 LB/HR
AIR LOAD FACTOR        1.1702            PATTERN FACTOR           .57281
BOT HOT SPOT: # 21 = 1546.   DEG F       MAX BOT / AVG BOT       1.3912
FUEL INLET TEMPERATURE 112.  DEG F       FUEL INLET PRESSURE      230.2  PSIA
HEAT LOADING PARAMETER  .38668E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1210.   6  954. 15  942. 19 1213. 24  912. 27  985. 36 1107.
ANNULUS 2   4 1019.   7  949. 16 1027. 21 1546. 25  870. 34 1324. 37 1174.
ANNULUS 3   5  911.  14 1077. 17 1042. 22 1397. 26  987. 35 1223. 38 1407.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE            54.89    PSIA    TOTAL PRESSURE          54.92   PSIA
STATIC PRESSURE           54.58    PSIA    STATIC PRESSURE         54.50   PSIA
VELOCITY DELTA P            .64     "HG    VELOCITY DELTA P          .71    "HG
AIR TEMPERATURE            352.  DEG F     AIR TEMPERATURE          352.  DEG F
AIR VELOCITY             126.65 FT/SEC     AIR VELOCITY           133.27 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.069     "HG

AIR FLOW DATA: P-NET= 104.0 PSIA    DELTA P= 2.31 "HG    T-REF=  82. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       360.      HZ      VOLUMETRIC FLOW RATE  15.73 GAL/HR
FUEL PRESSURE AT F/M   343.0     PSIA      FUEL TEMP AT F/M          85.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    52.80 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE            53.40 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.07  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.205 %      O2  18.200 %       CO    214.1 PPM     CHX      2.1 PPM
 NO     15.5 PPM   NO2     18.2 PPM   NOX     33.7 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2       .0 PPM   NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  17.37                    CHX=    .27
                    CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   4.40

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .010806
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.0006 %
   CHECK ON F/A RATIO- F/A = .010640 W/O O2, CALCULATED O2 = 17.911 %

SMOKE INDEX: 46.58
SALTZMAN NOX = 43.2            PPM     E.I.= 5.76
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Figure 360. Final Modified Conventional Liner, Initial Design, at Nonregenerative 25% Power - Open Setting

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T63 COMBUSTOR EXPERIMENTS - RIG P/O 46, TEST SERIES 55, READING #    726
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE,
TEST DATE: 6-22-72                         READING WAS TAKEN AT 160812Z HOURS

CYCLE POINT  5    VARIABLE GEOMETRY   0 % CLOSED       40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.503 LB/SEC     AVG BURNER INLET TEMP    396. DEG F
AVG BURNER INLET PRES   63.7   PSIA       AVG BURNER OUTLET TEMP  1205. DEG F
AVG BURNER DELTA P       4.58   "HG       PRESSURE LOSS             3.53 %
OVERALL F/A RATIO        .01320  (F/F)    FUEL FLOW RATE          110.95 LB/HR
AIR LOAD FACTOR          1.1497           PATTERN FACTOR           .49668
HOT HOT SPOT: # 21 = 1607.  DEG F         MAX BOT / AVG BOT        1.3334
FUEL INLET TEMPERATURE 110.  DEG F        FUEL INLET PRESSURE     250.1  PSIA
HEAT LOADING PARAMETER  .48481E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1328.  6 1075. 15 1052. 18 1334. 24 1023. 27 1042. 36 1144.
ANNULUS 2   4 1126.  7 1094. 16 1134. 21 1607. 25  962. 34 1302. 37 1217.
ANNULUS 3   5 1027. 14 1246. 17 1124. 22 1475. 26 1100. 35 1200. 39 1347.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          63.69   PSIA    TOTAL PRESSURE         63.71   PSIA
STATIC PRESSURE         63.31   PSIA    STATIC PRESSURE        63.37   PSIA
VELOCITY DELTA P          .77    "HG    VELOCITY DELTA P         .70    "HG
AIR TEMPERATURE         396.  DEG F     AIR TEMPERATURE        396.  DEG F
AIR VELOCITY          132.80 FT/SEC     AIR VELOCITY         125.00 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.040   "HG

AIR FLOW DATA: P-REF= 184.2 PSIA   DELTA P= 2.07 "HG   T-REF=  82. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       437.      HZ     VOLUMETRIC FLOW RATE  18.13 GAL/HR
FUEL PRESSURE AT F/M   456.0    PSIA      FUEL TEMP AT F/M        87.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    61.48 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             62.01 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.55  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    2.401 %     O2  17.000 %     CO    186.3 PPM      CHX       .0 PPM
 NO     33.0 PPM  NO2    24.0 PPM  NOX     57.0 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2      .0 PPM  NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  14.57                    CHX=   .11
              CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   8.08

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011487
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8607 %
   CHECK ON F/A RATIO- F/A = .011500 W/O O2, CALCULATED O2 = 17.037 %

SMOKE INDEX: 52.74
SALTZMAN NOX = 54.5                PPM   E.I. = 6.65
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Figure 361. Final Modified Conventional Liner, Initial Design, at Nonregenerative 40% Power - Open Setting.

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TF3 COMBUSTOR EXPERIMENTS - RIG B/U 46, TEST SERIES 55, READING #    787
TF3 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72                         READING WAS TAKEN AT 1821:56 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY 100 % CLOSED       40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.515 LB/SEC    AVG BURNER INLET TEMP   397. DEG F
AVG BURNER INLET PRES  63.8     PSIA     AVG BURNER OUTLET TEMP 1232. DEG F
AVG BURNER DELTA P      6.16    "HG      PRESSURE LOSS            4.75 %
OVERALL F/A RATIO      .01310  (F/P)     FUEL FLOW RATE         118.59 LB/HR
AIR LOAD FACTOR        1.1540            PATTERN FACTOR          .23049
BOT HOT SPOT: # 21 = 1431.  DEG F        MAX BOT / AVG BOT      1.1617
FUEL INLET TEMPERATURE 122.  DEG F       FUEL INLET PRESSURE     259.3  PSIA
HEAT LOADING PARAMETER  .40310E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1225.  6 1177. 15 1111. 19 1202. 24 1160. 27 1257. 30 1157.
ANNULUS 2   4 1115.  7 1218. 16 1150. 21 1431. 25 1201. 34 1301. 37 1101.
ANNULUS 3   5 1144. 14 1194. 17 1200. 22 1392. 26 1252. 35 1321. 39 1203.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          63.77    PSIA    TOTAL PRESSURE          63.70   PSIA
STATIC PRESSURE         63.44    PSIA    STATIC PRESSURE         63.37   PSIA
VELOCITY DELTA P          .66    "HG     VELOCITY DELTA P          .64   "HG
AIR TEMPERATURE          396.  DEG F     AIR TEMPERATURE          397.  DEG F
AIR VELOCITY           122.70 FT/SEC     AIR VELOCITY           130.13 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.025   "HG

AIR FLOW DATA: P-REF= 104.1 PSIA    DELTA P= 2.89 "HG    T-REF=  81. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      436.      HZ      VOLUMETRIC FLOW RATE  19.09 GAL/HR
FUEL PRESSURE AT F/M  485.6     PSIA      FUEL TEMP AT F/M         80.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    60.75 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              62.02 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.15  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.550 %      O2  17.000 %      CO    101.2 PPM     CHX       .7 PPM
 NO     20.5 PPM   NO2     6.9 PPM   NOX     30.4 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2      .0 PPM   NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   7.97                     CHX=    .30
                 CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=    4.72

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .012130
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7000 %
   CHECK ON F/A RATIO= F/A = .012200 W/O O2, CALCULATED O2 = 17.440 %

SMOKE INDEX: 11.42
SALTZMAN NOX =  43.8              PPM      E.I. = 5.38
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Figure 362. Final Modified Conventional Liner, Initial Design, at Nonregenerative 40% Power - Closed Setting.

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TF3 COMBUSTOR EXPERIMENTS - RIG F/U 40, TEST SERIES 55, READING #    720
TF3 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72                       READING WAS TAKEN AT 1652: 7 HOURS

CYCLE POINT  4    VARIABLE GEOMETRY 100 % CLOSED       55 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.773 LB/SEC    AVG BURNER INLET TEMP    430. DEG F
AVG BURNER INLET PRES  72.0    PSIA      AVG BURNER OUTLET TEMP 1340. DEG F
AVG BURNER DELTA P       6.95    "HG     PRESSURE LOSS             4.74 %
OVERALL F/A RATIO       .01444  (F/P)    FUEL FLOW RATE          144.20 LB/HR
AIR LOAD FACTOR         1.1491           PATTERN FACTOR           .23945
BOT HOT SPOT: # 21 = 1550.  DEG F        MAX BOT / AVG BOT       1.1627
FUEL INLET TEMPERATURE 132.  DEG F       FUEL INLET PRESSURE     384.0  PSIA
HEAT LOADING PARAMETER  .43430E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1320.  6 1259. 15 1234. 19 1404. 24 1230. 27 1324. 36 1251.
ANNULUS 2   4 1213.  7 1314. 16 1291. 21 1550. 25 1278. 34 1437. 37 1272.
ANNULUS 3   5 1235. 14 1392. 17 1338. 22 1510. 26 1337. 35 1412. 39 1479.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          71.97    PSIA    TOTAL PRESSURE          71.00   PSIA
STATIC PRESSURE         71.00    PSIA    STATIC PRESSURE         71.00   PSIA
VELOCITY DELTA P          .75    "HG     VELOCITY DELTA P          .80    "HG
AIR TEMPERATURE         430.  DEG F      AIR TEMPERATURE         430.  DEG F
AIR VELOCITY          125.30 FT/SEC      AIR VELOCITY          129.41 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.090    "HG

AIR FLOW DATA: P-REF= 1*3.7 PSIA   DELTA P= 3.53 "HG    T-REF= 79. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       531.       HZ    VOLUMETRIC FLOW RATE  23.24 GAL/HR
FUEL PRESSURE AT F/M   566.2    PSIA      FUEL TEMP AT F/M          81.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    60.50 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             69.00 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.94  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   2.051 %     O2   17.200 %     CO     67.3 PPM       CHX       .6 PPM
 NO    40.8 PPM   NO2    12.3 PPM   NOX    53.1 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM   NO2      .0 PPM   NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  5.93                    CHX=     .06
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    5.93

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .013524
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.0200 %
   CHECK ON F/A RATIO- F/A = .013637 W/O O2, CALCULATED O2 = 17.021 %

SMOKE INDEX: 20.46
SALTZMAN NOX = X                 PPM
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Figure 363. Final Modified Conventional Liner, Initial Design, at Nonregenerative 55% Power - Closed Setting.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 46, TEST SERIES 55, READING #    701
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE:  6-22-72                           READING WAS TAKEN AT 172911O HOURS

CYCLE POINT  4     VARIABLE GEOMETRY    0 % CLOSED       55 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.736 LB/SEC     AVG BURNER INLET TEMP    431. DEG F
AVG BURNER INLET PRES  71.3    PSIA       AVG BURNER OUTLET TEMP 1313. DEG F
AVG BURNER DELTA P      5.17   "HG        PRESSURE LOSS              3.56 %
OVERALL F/A RATIO      .01455  (F/F)      FUEL FLOW RATE           143.16 LB/HR
AIR LOAD FACTOR        1.1451             PATTERN FACTOR           .43071
BOT HOT SPOT:  # 21 = 1692.  DEG F        MAX BOT / AVG BOT        1.2804
FUEL INLET TEMPERATURE 133.  DEG F        FUEL INLET PRESSURE      381.   PSIA
HEAT LOADING PARAMETER  .43525E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1446.  6 1233. 15 1098. 19 1492. 24 1137. 27 1290. 36 1234.
ANNULUS 2   4 1238.  7 1240. 16 1208. 21 1692. 25 1090. 34 1424. 37 1312.
ANNULUS 3   5 1132. 14 1319. 17 1225. 22 1604. 26 1247. 35 1318. 39 1675.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          71.28    PSIA     TOTAL PRESSURE         71.32   PSIA
STATIC PRESSURE         70.89    PSIA     STATIC PRESSURE        70.86   PSIA
VELOCITY DELTA P          .80    "HG      VELOCITY DELTA P         .94    "HG
AIR TEMPERATURE          431.   DEG F     AIR TEMPERATURE         431.  DEG F
AIR VELOCITY           129.84 FT/SEC      AIR VELOCITY          140.97 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.083    "HG

AIR FLOW DATA: P-REF= 103.8 PSIA    DELTA P= 3.42 "HG    T-REF=  78. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      528.       HZ     VOLUMETRIC FLOW RATE  23.11 GAL/HR
FUEL PRESSURE AT F/M  580.9      PSIA     FUEL TEMP AT F/M         93.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    68.76 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             69.53 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.13  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.650 %      O2  17.200 %     CO    211.9 PPM      CHX       .7 PPM
 NO     39.4 PPM   NO2     20.4 PPM   NOX     59.8 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM   NO2       .0 PPM   NOX       .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  14.30                    CHX=    .07
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   6.63

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .012863
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.5982 %
   CHECK ON F/A RATIO- F/A = .012749 W/O O2. CALCULATED O2 = 17.290 %

SMOKE INDEX: 64.91
SALTZMAN NOX = X                         PPM
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Figure 364. Final Modified Conventional Liner, Initial Design, at Nonregenerative 55% Power - Open Setting.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 46, TEST SERIES 55, READING #    732
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72                         READING WAS TAKEN AT 1758:12 HOURS

CYCLE POINT  3    VARIABLE GEOMETRY 100 % CLOSED       75 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW            2.938 LB/SEC     AVG BURNER INLET TEMP    472. DEG F
AVG BURNER INLET PRES   80.7     PSIA     AVG BURNER OUTLET TEMP 1495. DEG F
AVG BURNER DELTA P        7.22     "HG      PRESSURE LOSS              4.39 %
OVERALL F/A RATIO       .01657   (F/M)     FUEL FLOW RATE           175.26 LB/HR
AIR LOAD FACTOR         1.1110              PATTERN FACTOR           .26835
HOT HOT SPOT: * 39 = 1767.  DEG F         MAX BOT / AVG BOT         1.1816
FUEL INLET TEMPERATURE 144.  DEG F         FUEL INLET PRESSURE      365.3  PSIA
HEAT LOADING PARAMETER  .47079E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1476.  6 1430. 15 1348. 19 1543. 24 1384. 27 1498. 36 1368.
ANNULUS 2   4 1356.  7 1489. 16 1361. 21 1738. 25 1449. 34 1602. 37 1483.
ANNULUS 3   5 1345. 14 1582. 17 1456. 22 1722. 26 1513. 35 1588. 39 1767.

LEFT SIDE               *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE            80.73    PSIA     TOTAL PRESSURE          80.78   PSIA
STATIC PRESSURE           80.33    PSIA     STATIC PRESSURE         80.12   PSIA
VELOCITY DELTA P            .83    "HG      VELOCITY DELTA P         1.19    "HG
AIR TEMPERATURE           472.   DEG F      AIR TEMPERATURE          472.  DEG F
AIR VELOCITY            127.70 FT/SEC      AIR VELOCITY           152.48 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]             .074    "HG

AIR FLOW DATA: P-REF= 103.2 PSIA   DELTA P= 3.97 "HG    T-REF=  78. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        649.      HZ     VOLUMETRIC FLOW RATE  28.34 GAL/HR
FUEL PRESSURE AT F/M   551.7    PSIA     FUEL TEMP AT F/M          96.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   77.17 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             78.58 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.25  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    3.287 %     O2   16.500 %      CO     85.3 PPM     CHX       .4 PPM
 NO     55.0 PPM  NO2     14.7 PPM   NOX     69.7 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM   NOX       .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    5.06                  CHX=     .04
                  CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   6.79

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .015616
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8490 %
   CHECK ON F/A RATIO  F/A = .015679 W/O O2, CALCULATED O2 = 16.415 %

SMOKE INDEX: 38.49
SALTZMAN NOX =  X                   PPM
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Figure 365. Final Modified Conventional Liner, Initial Design, at Nonregenerative 75% Power - Closed Setting.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 46, TEST SERIES 55, READING # 733
T63 MODIFIED CONVENTIONAL LINER WITH VARIABLE GEOMETRY DILUTION ZONE.
TEST DATE: 6-22-72 READING WAS TAKEN AT 1814:10 HOURS

CYCLE POINT 2 VARIABLE GEOMETRY 100 % CLOSED 100 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	3.229 LB/SEC	AVG BURNER INLET TEMP	522. DEG F
AVG BURNER INLET PRES	91.8 PSIA	AVG BURNER OUTLET TEMP	1724. DEG F
AVG BURNER DELTA P	7.91 "HG	PRESSURE LOSS	4.23 %
OVERALL F/A RATIO	.01960 (F/M)	FUEL FLOW RATE	227.84 LB/HR
AIR LOAD FACTOR	1.1016	PATTERN FACTOR	.28989
BOT HOT SPOT: # 22 = 2073. DEG F		MAX BOT / AVG BOT	1.2021
FUEL INLET TEMPERATURE 154. DEG F		FUEL INLET PRESSURE	493.6 PSIA

HEAT LOADING PARAMETER .53782E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1627.	6	1667.	15	1556.	19	1778.	24	1640.	27	1699.	36	1532.
ANNULUS 2	4	1558.	7	1800.	16	1576.	21	2010.	25	1681.	34	1776.	37	1587.
ANNULUS 3	5	1639.	14	1857.	17	1655.	22	2073.	26	1739.	35	1761.	39	2064.

LEFT SIDE *** AIR INLET TUBE CONDITIONS *** RIGHT SIDE

TOTAL PRESSURE	91.82 PSIA	TOTAL PRESSURE	91.85 PSIA
STATIC PRESSURE	91.30 PSIA	STATIC PRESSURE	91.16 PSIA
VELOCITY DELTA P	1.07 "HG	VELOCITY DELTA P	1.40 "HG
AIR TEMPERATURE	522. DEG F	AIR TEMPERATURE	522. DEG F
AIR VELOCITY	139.03 FT/SEC	AIR VELOCITY	159.16 FT/SEC

DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.052 "HG

AIR FLOW DATA: P-REF= 102.8 PSIA DELTA P= 4.82 "HG T-REF= 76. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	849. HZ	VOLUMETRIC FLOW RATE	36.88 GAL/HR
FUEL PRESSURE AT F/M	546.5 PSIA	FUEL TEMP AT F/M	98. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 87.95 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 89.70 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 7.89 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 3.867 % O2 15.700 % CO 62.0 PPM CHX .5 PPM
NO 95.8 PPM NO2 17.2 PPM NOX 112.9 PPM (NO(NDIR) + NO2(NDUV))
NO .0 PPM NO2 .0 PPM NOX .0 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 3.12 CHX= .04
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 9.33

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .018296
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.8826 %
CHECK ON F/A RATIO- F/A = .018375 W/O O2, CALCULATED O2 = 15.688 %

SMOKE INDEX: 51.65
SALTZMAN NOX = X PPM

Figure 366. Final Modified Conventional Liner, Initial Design, at Nonregenerative 100% Power - Closed Setting.

TABLE LXXXIII. COMPARISON OF T63 NONREGENERATIVE EMISSION/COMBUSTOR PERFORMANCE OF (1) CONVENTIONAL LINER, AND FINAL DESIGN MODIFIED CONVENTIONAL LINER (2) DILUTION ZONE OPEN SETTING AND (3) DILUTION ZONE CLOSED SETTING

	Cycle Point					
	1	6	5	4	3	2
I. Conventional Liner						
A. Emissions						
CO, (ppm)	892.7	651.5	495.5	382.9	214.1	74.7
H/C, (ppm)	100.0	37.0	15.8	4.1	0.7	0.6
NO_x, (On-Line, NDIR & NDUV) (ppm)	17.0	32.0	41.1	45.6	58.0	81.0
NO_x, (On-Line, CL) (ppm)	17.2	23.4	32.6	40.7	56.3	80.6
No_x, (Saltzman) (ppm)	18.5	27.8	37.1	45.8	61.3	90.6
Smoke Number	3.	7.	12.	17.	25.	30.
B. Pressure Loss (%)	4.63	4.51	4.53	4.44	4.38	4.14
C. Temp. Profile (T_{max}/T_{avg})	1.115	1.142	1.120	1.113	1.104	1.065
II. Final Design Modified Conventional Liner DZ Open Setting						
A. Emissions						
CO, (ppm)	223.4	214.1	196.3	211.8	NO DATA TAKEN	NO DATA TAKEN
H/C, (ppm)	6.5	2.1	.9	.7		
NO_x, (On-Line, NDIR & NDUV) (ppm)	26.9	33.7	57.0	59.8		
NO_x, (Saltzman) (ppm)						
Smoke Number	29.07	46.58	52.74	64.91		
B. Pressure Loss (%)	3.72	3.67	3.53	3.56		
C. Temp. Profile (T_{max}/T_{avg})	1.434	1.391	1.333	1.289		
III. Final Design Modified Conventional Liner DZ Closed Setting						
A. Emissions						
CO, (ppm)	250.0	150.8	101.2	87.3	85.3	62.0
H/C, (ppm)	10.0	2.5	.7	.6	.4	.5
NO_x, (On-Line, NDIR & NDUV) (ppm)	23.4	24.5	38.4	53.1	69.7	112.9
NO_x, (Saltzman) (ppm)						
Smoke Number	1.34	5.86	11.42	20.46	38.49	51.65
B. Pressure Loss (%)	4.99	4.86	4.75	4.74	4.39	4.23
C. Temp. Profile (T_{max}/T_{avg})	1.157	1.177	1.162	1.163	1.182	1.202

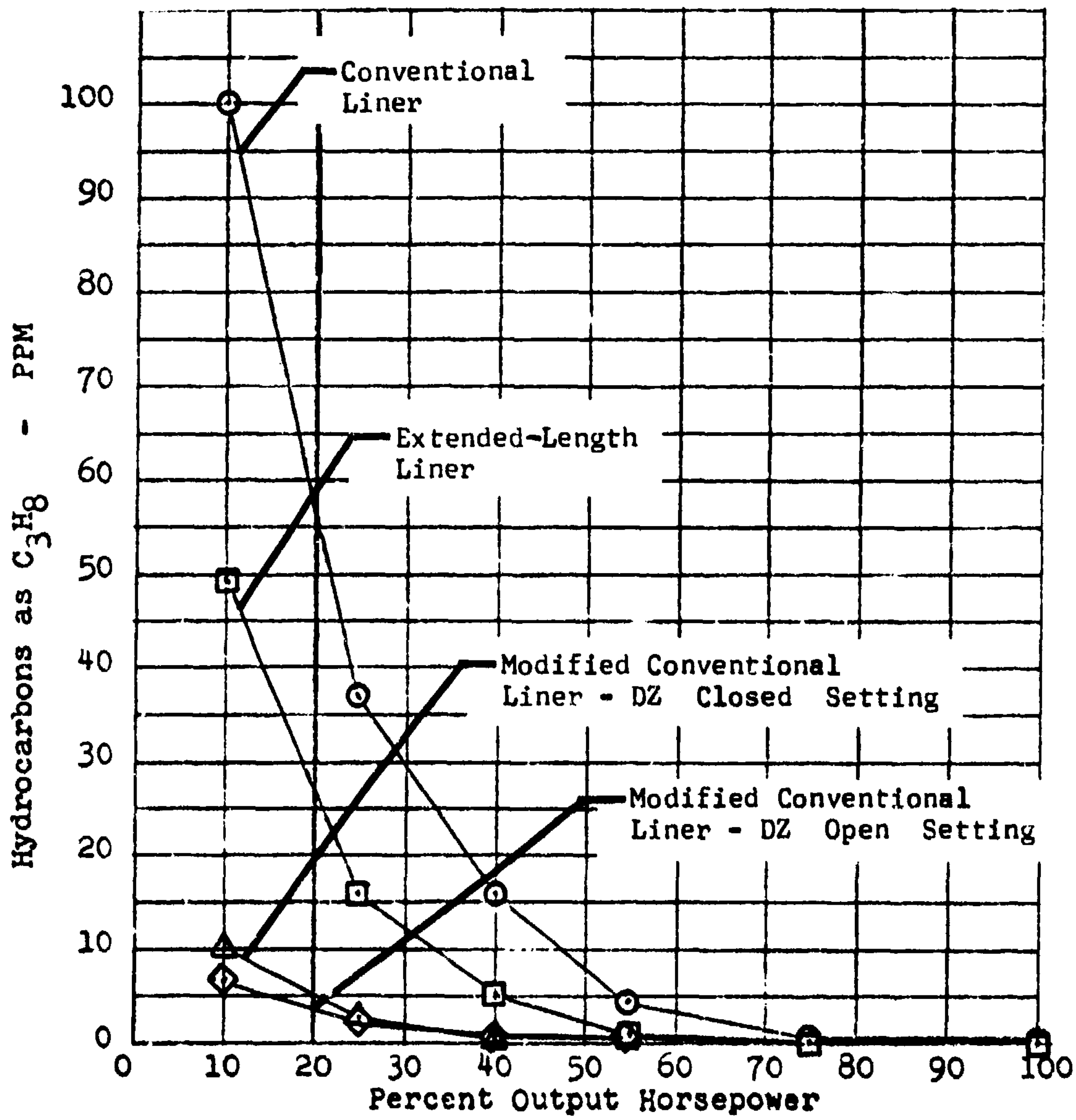

Figure 367. Nonregenerative T63-A-5A Combustor Hydrocarbon Emissions Data Comparison for Standard-Length, Modified-Conventional, Final Design Combustor and T63 Baseline Combustors.

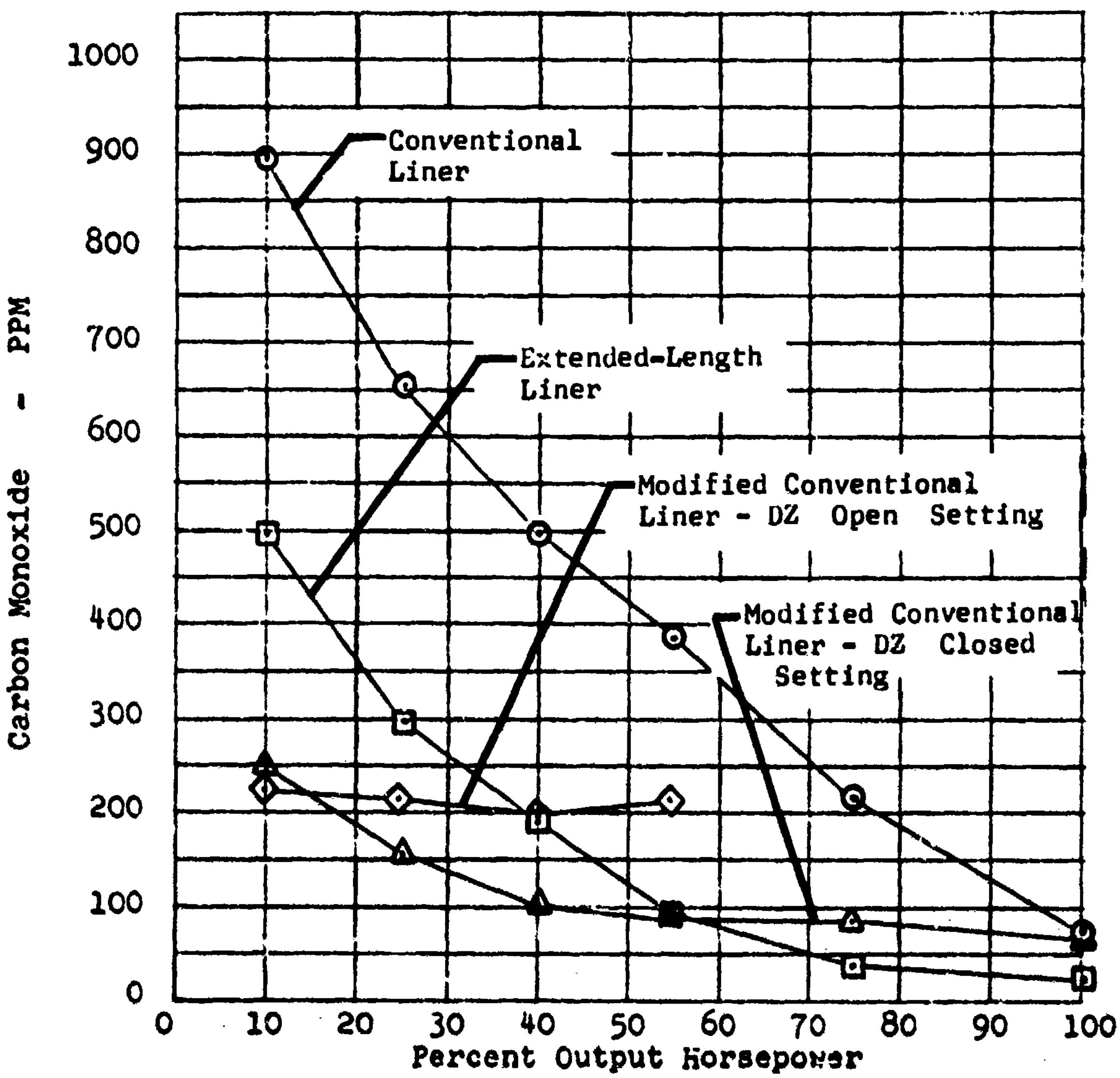

Figure 368. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Standard-Length, Modified-Conventional, Final Design Combustor and T63 Baseline Combustors.

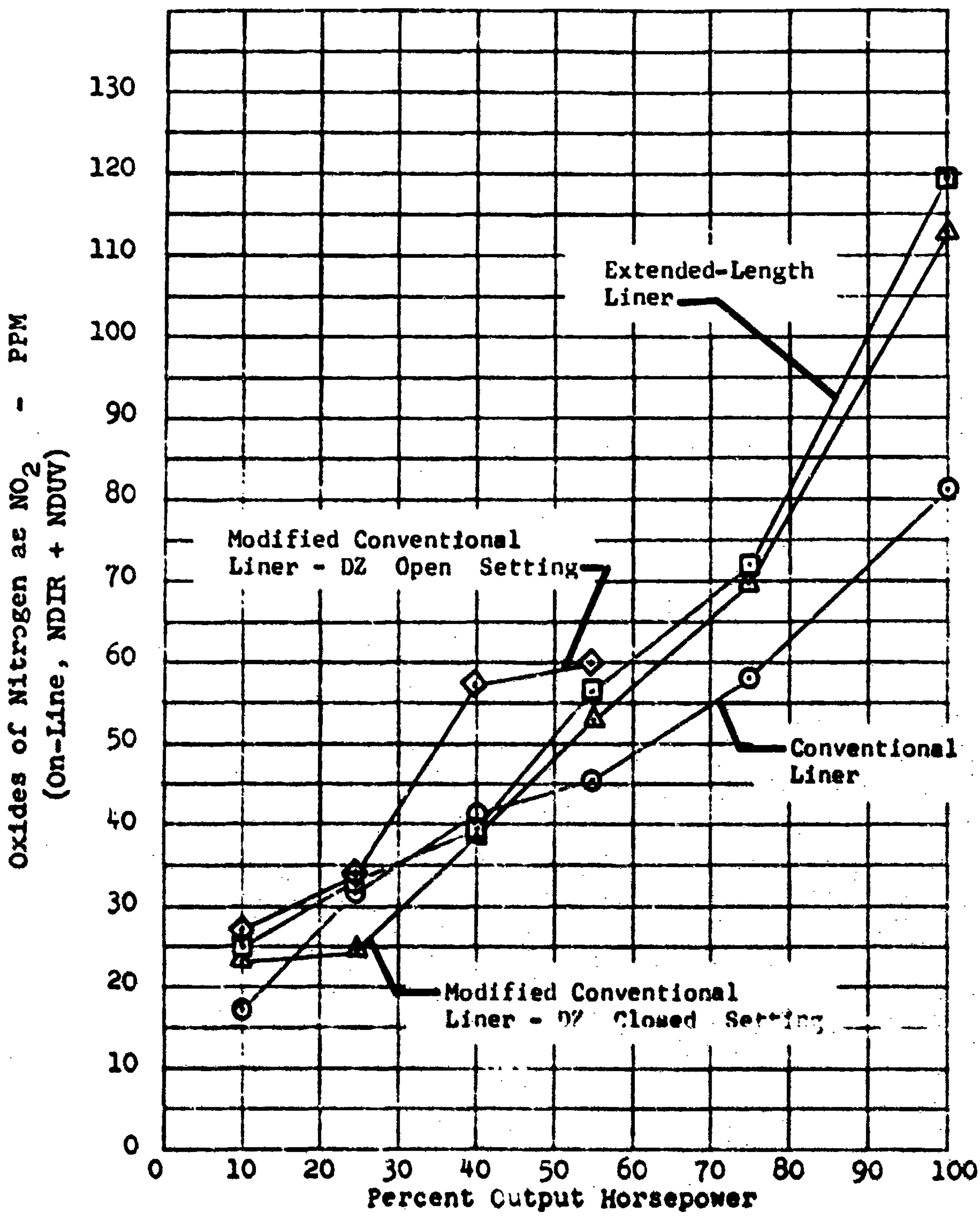

Figure 369. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Standard-Length, Modified-Conventional, Final Design Combustor and T63 Baseline Combustors.

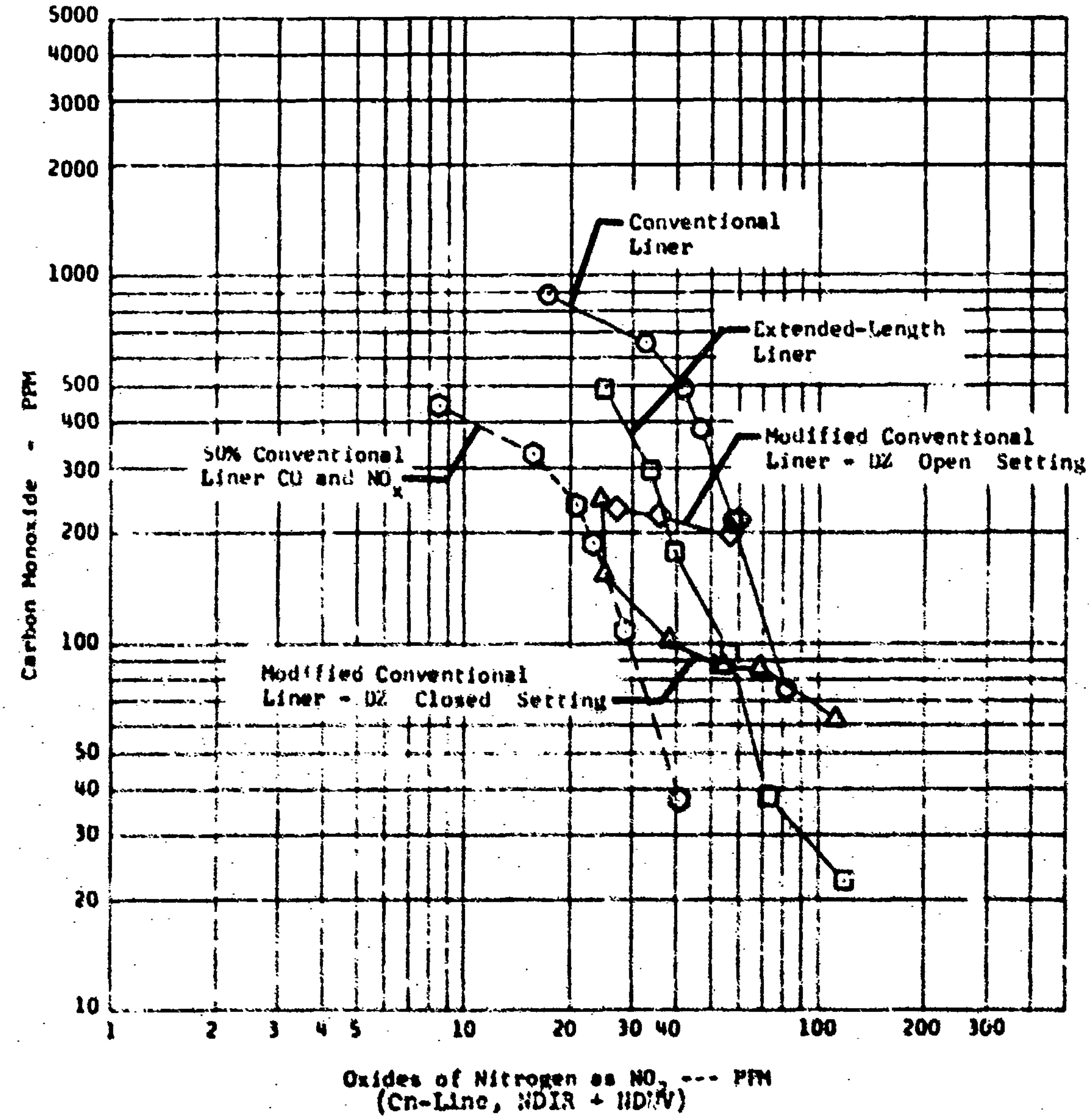

Figure 370. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Standard-Length, Modified-Conventional, Final Design Combustor and T63 Baseline Combustors.

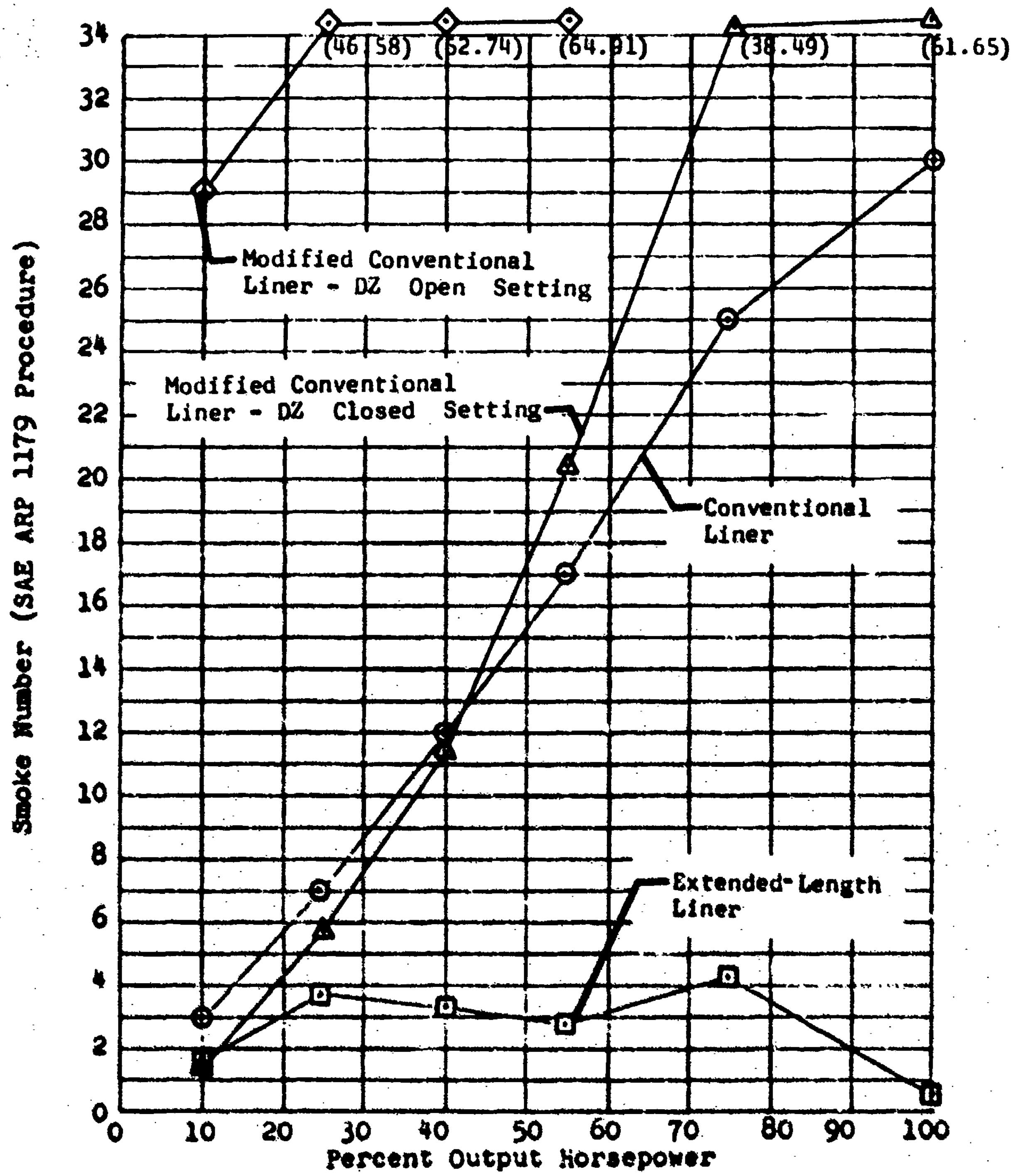

Figure 371. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Standard-Length, Modified-Conventional, Final Design Combustor and T63 Baseline Combustors.

74% and hydrocarbons 90%. Both NO_x and particulates increased above the Conventional T63 levels. The NO_x emissions were 18% higher than the baseline level, and particulates were 83% higher. Even though the contract objective of 50% minimum reduction in total emissions was met in this design, the requirement that no constituent emission could increase was not met.

Exhaust temperature profile results for the Modified Conventional combustor are plotted in Figure 372. The closed dilution setting temperature profiles were in general no worse than those from the Extended-Length combustor, but the profiles were definitely worse than those from the Conventional T63 combustor, especially at the higher power operating conditions.

The skin thermocouple readings for the Modified Conventional combustor liner are shown in Figure 373 for the open dilution setting and in Figure 374 for the closed setting. The combustor metal temperatures along the primary zone were considerably higher when the dilution slip band was set at the open setting.

Because of the poor exhaust temperature profiles from the Modified Conventional combustor, lampblack cold-flow tracings of the combustor airflow characteristics were recorded for both dilution settings. Figure 375 is the flow tracing for the open position, and Figure 376 shows the closed position tracing. Comparing these flow tracings reveals that the additional pressure loss resulting from the closed position of the dilution band produced much better mixing and deeper penetration of the inlet air through both the primary and dilution holes. It was therefore apparent that pressure losses of less than 4% would result in poor combustor performance.

Modification "A"

The changes to the Modified Conventional combustor resulting in Modification "A" were all made in the dilution zone. The combustor was rebuilt downstream of the dilution film cooling annulus to incorporate the following design revisions:

- The dilution-hole axial location was moved 2.00 inches upstream to the same axial position as the two dilution holes in the Conventional T63-A-5A combustor liner.
- The two sets of six dilution holes in the variable-geometry slip band were replaced with a single set of six 1.22-inch-square holes with 0.41-inch-radius corner fillets.
- Due to additional space required for the variable-geometry slip band, the dilution-zone film cooling section was reworked.

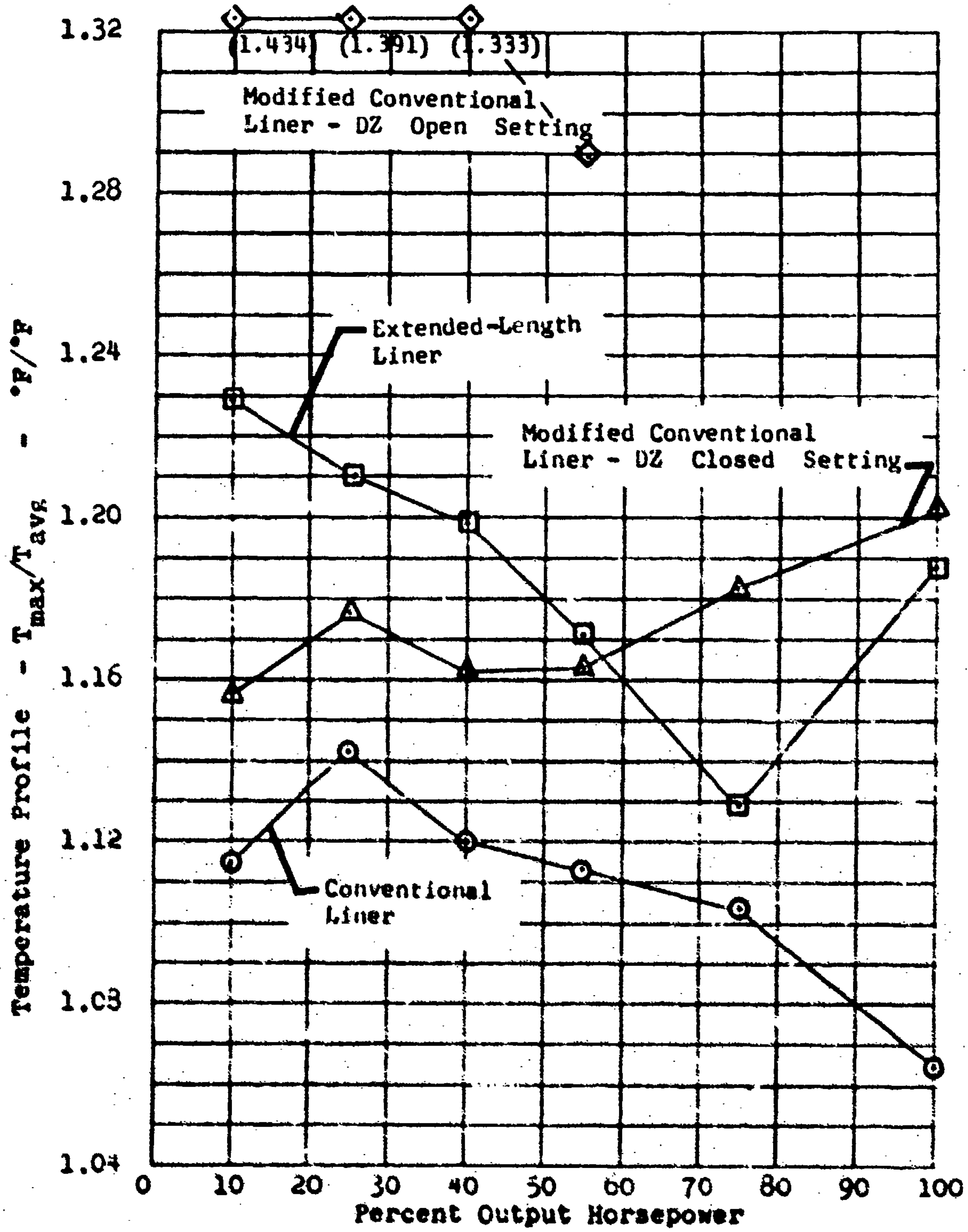

Figure 372. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Standard-Length, Modified-Conventional, Final Design Combustor and T63 Baseline Combustors.

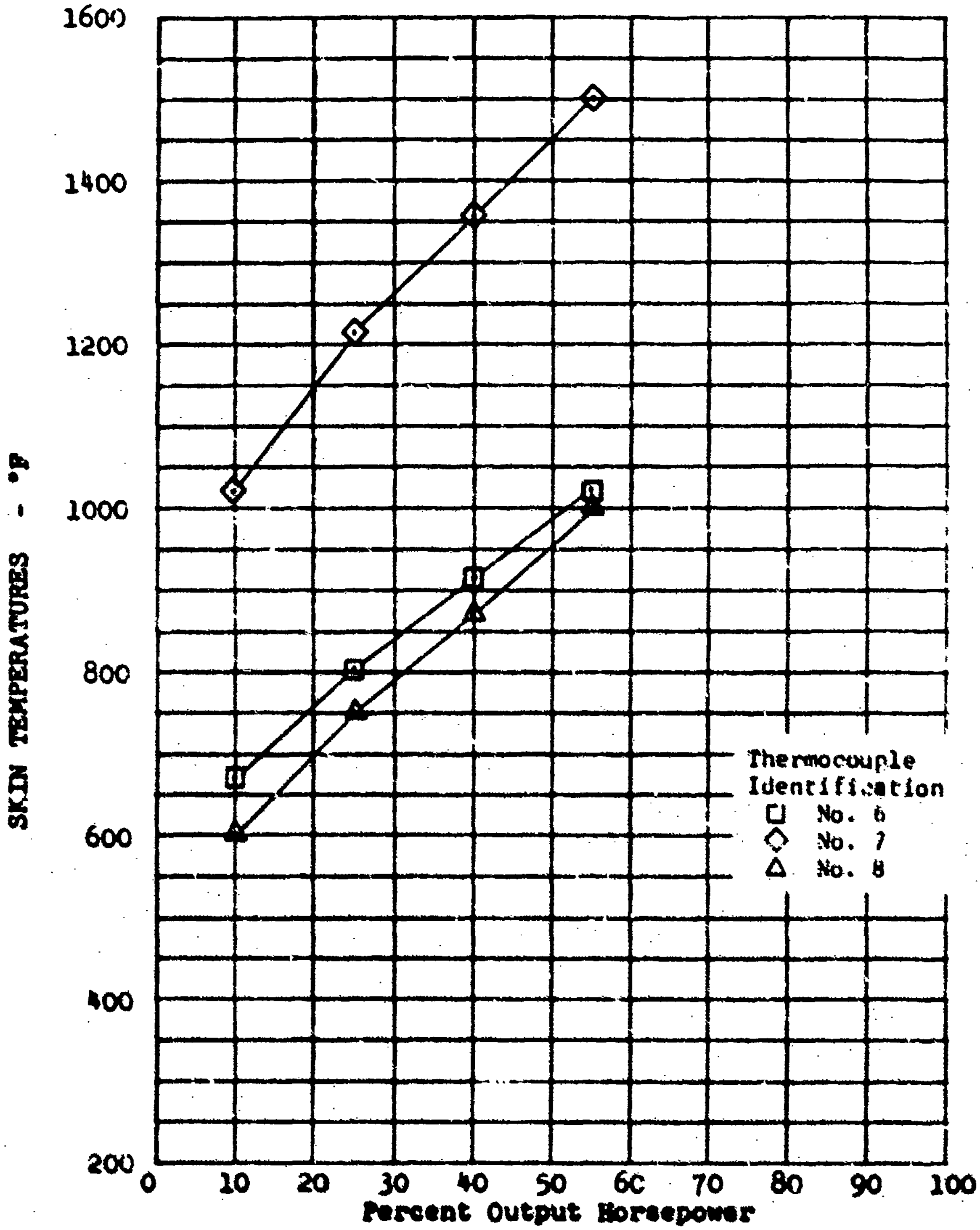

Figure 373. Nonregenerative T63-A-5A Combustor Skin Temperatures for Modified Conventional Final Design Combustor Operating at DZ Open Setting.

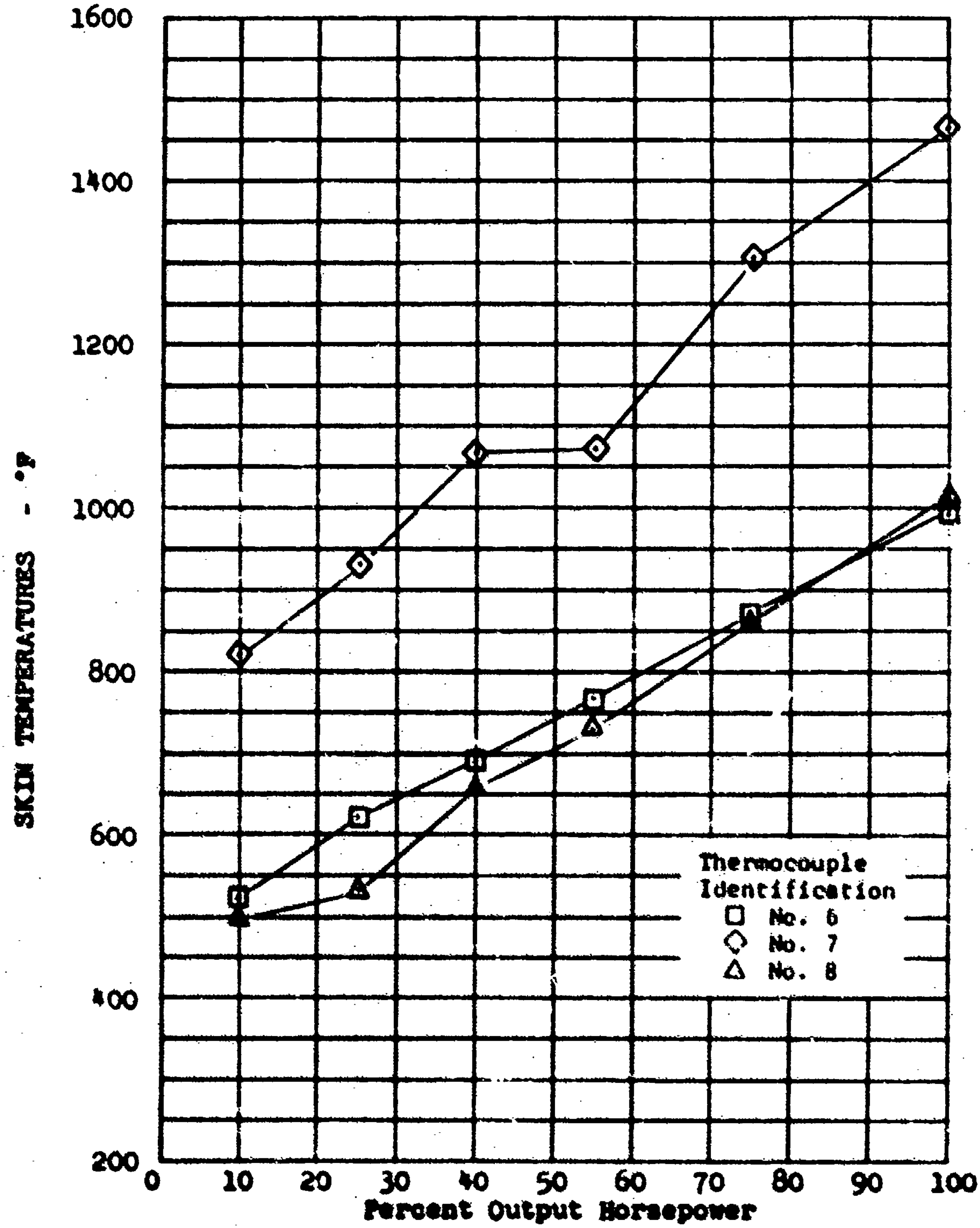

Figure 374. Nonregenerative T63-A-5A Combustor Skin Temperatures for Modified Conventional Final Design Combustor Operating at DZ Closed Setting.

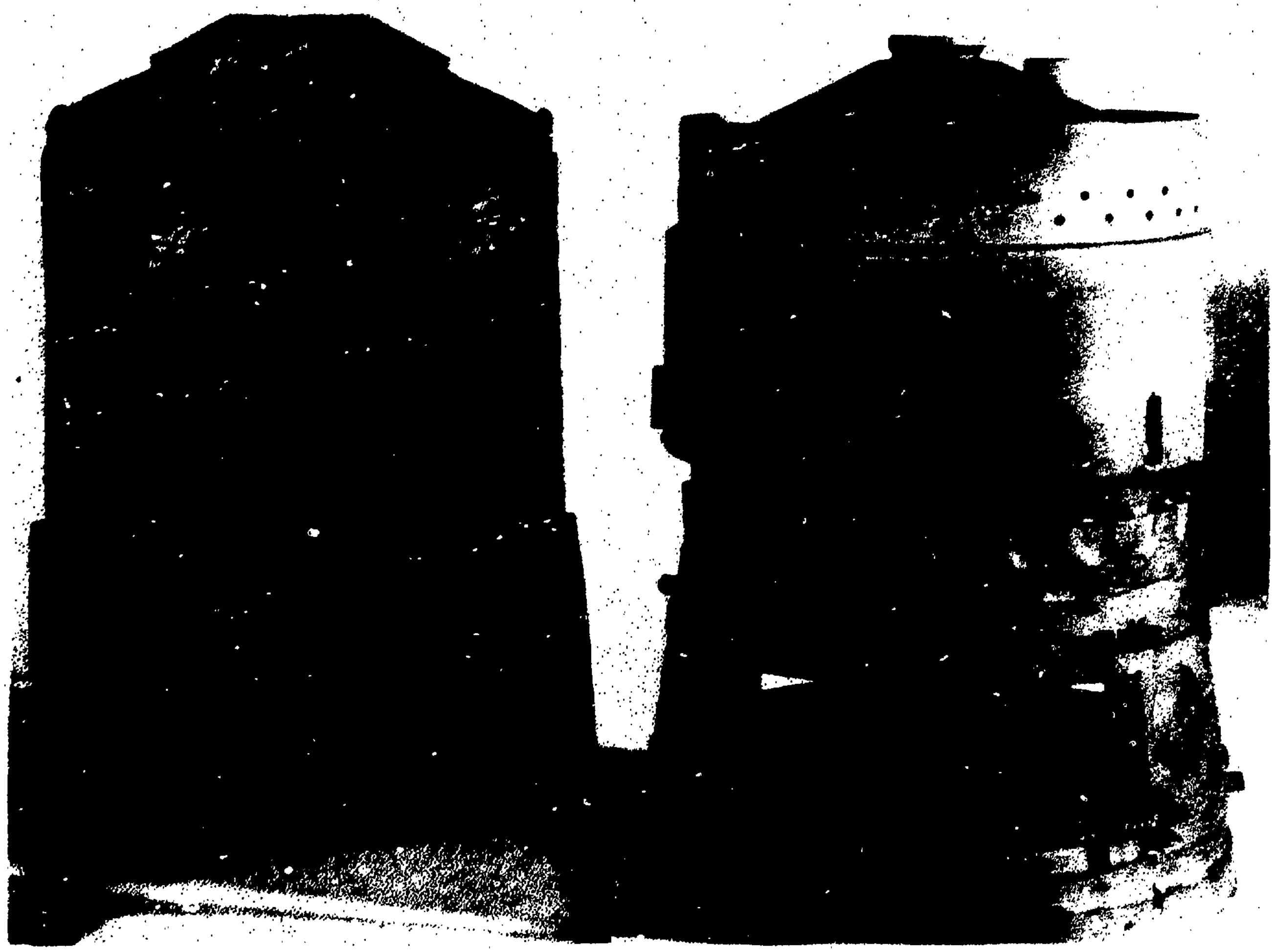

Figure 375. Final Modified Conventional Liner Cold Flow Tracings for Open Dilution Sett.ng.

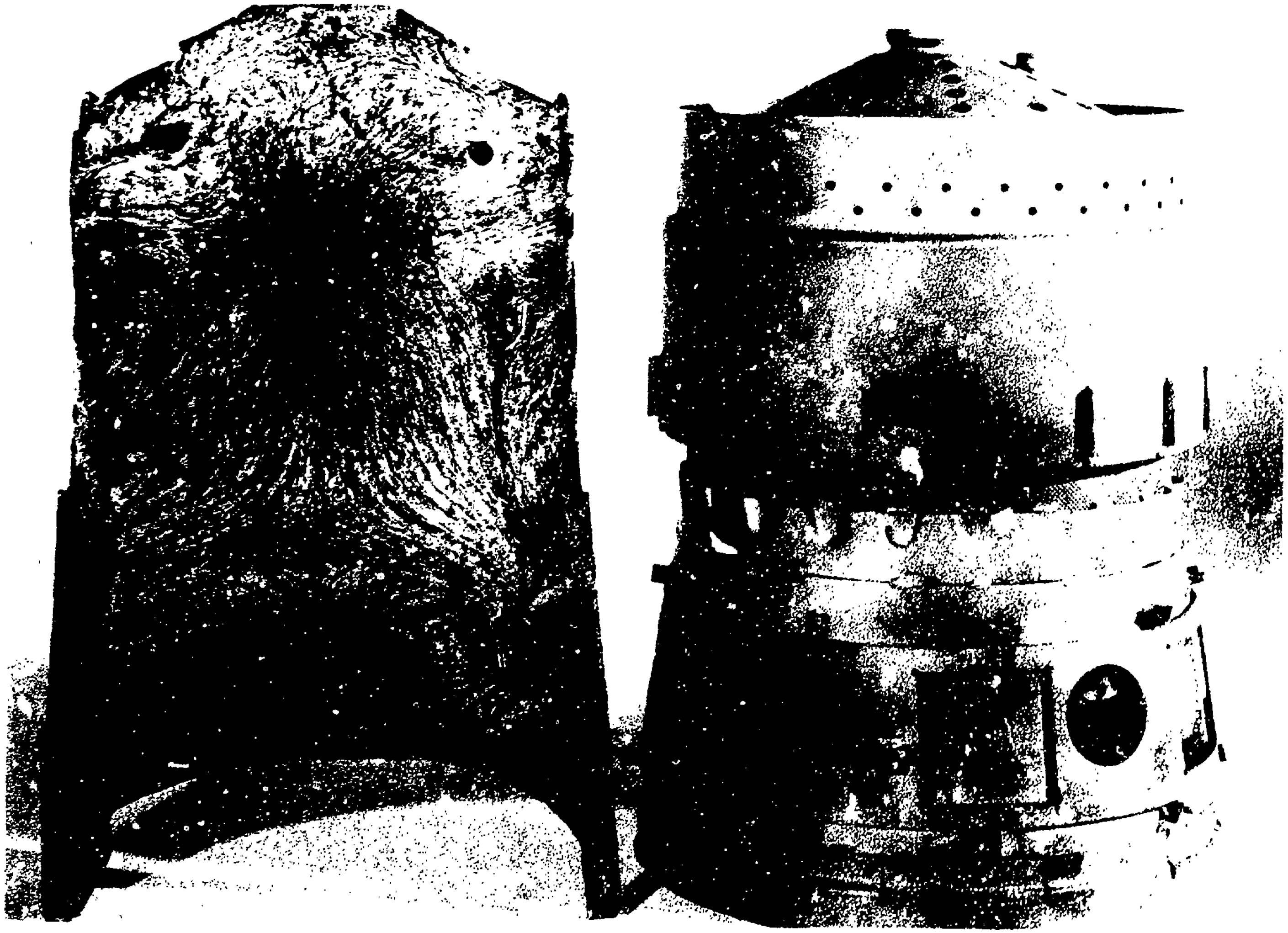

Figure 376. Final Modified Conventional Liner Cold Flow Tracings for Closed Dilution Setting.

The purpose of the liner modifications was to reduce the residence time in the predilution zone to limit the amount of NO_x formed and to give additional mixing volume for the dilution air to improve the exhaust temperature profile.

The Modification "A" combustor was tested at nonregenerative T63 conditions using three geometry settings of the dilution slip band: 32%, 50%, and 70% closed. The 32% closed position was to give the same flow split between primary and dilution zones as in the Conventional T63 combustor liner. The regenerative setting corresponded to the 0% closed or full open position. The 50% and 70% closed positions were marked so that they could be used to control NO_x generation by further leaning of the primary zone.

The test data recorded during the nonregenerative testing of the Modified Conventional Modification "A" combustor liner are presented in Figures 377 through 389. The emission, pressure-loss, and temperature-profile data are summarized in Table LXXXIV. Comparison of emissions and pressure loss data among the dilution geometry settings shows the lack of response of combustor performance to changes in the variable-geometry actuator rods. If the dilution slip band had rotated to effect a closing of the dilution holes from 32% to 70% closed, the pressure loss would have increased by much more than the 1% that was measured. Inspection of the combustor after the test revealed that the variable-geometry tabs connecting the actuator rods to the slip ring were severely deformed and thus must have yielded during each adjustment of the actuator rods. One of the bent tabs can be seen in Figure 352, a photograph which was taken after the test.

As noted in Table LXXXIV, no values for the nondispersion (ND) NO_x concentrations were given for cycle points 2, 3, and 4. During the test, the nondispersive ultraviolet (NDUV) instrument used to measure NO_2 concentrations could not be used, and thus only NO concentrations from the nondispersive infrared (NDIR) instrument were recorded. Total nitrogen oxides determined by the Saltzman wet chemistry method were used in the emission index calculations.

The emission data for the Modified Conventional Modification "A" combustor are compared with the Conventional T63 and Extended-Length combustor liners in Figures 390 through 393. Because of the lack of emission change with geometry setting, only the 32% closed setting data are connected. In Figure 390 are plotted the hydrocarbon data for Modification "A". The Modified Conventional hydrocarbon concentrations are considerably below the baseline levels and represent a 68% reduction. Carbon monoxide emissions, Figure 391, were not low enough in Modification "A" to enable the combustor to attain the 50% reduction in total emissions. The CO mass emissions were reduced by only 39%. Only the nitrogen oxide emissions are shown in Figure 392, since the NDUV on-line instrument could not be used

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    816
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS,
TEST DATE:  7-19-72                        READING WAS TAKEN AT 1889:24 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY  32 % CLOSED       10 % POWER SETTING

                       ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.868 LB/SEC    AVG BURNER INLET TEMP    299. DEG F
AVG BURNER INLET PRES   44.6    PSIA     AVG BURNER OUTLET TEMP 1010. DEG F
AVG BURNER DELTA P       3.66    "HG     PRESSURE LOSS             4.03 %
OVERALL F/A RATIO       .01089  (F/M)    FUEL FLOW RATE           73.23 LB/HR
AIR LOAD FACTOR         1.1531           PATTERN FACTOR           .36846
BOT HOT SPOT:  # 14 = 1272.  DEG F       MAX BOT / AVG BOT       1.2592
FUEL INLET TEMPERATURE 107.  DEG F       FUEL INLET PRESSURE     226.3   PSIA
HEAT LOADING PARAMETER   .35572E+07 BTU/HOUR/ATM/CUBIC FOOT

                     **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2  873.  6  521. 15 1200. 19  917. 24 1049. 27 1112. 36 1034.
ANNULUS 2    4  902.  7  9(2. 16 1190. 21  891. 25 1113. 34 1164. 37 1047.
ANNULUS 3    5  890. 14 1272. 17 1066. 22  918. 26 1117. 35 1004. 39  943.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE           44.62   PSIA    TOTAL PRESSURE           44.63   PSIA
STATIC PRESSURE          44.40   PSIA    STATIC PRESSURE          44.42   PSIA
VELOCITY DELTA P           .44    "HG    VELOCITY DELTA P           .43    "HG
AIR TEMPERATURE          299.  DEG F     AIR TEMPERATURE          300.  DEG F
AIR VELOCITY            112.75 FT/SEC    AIR VELOCITY            111.02 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.038    "HG

AIR FLOW DATA: P-REF= 105.3 PSIA    DELTA P= 1.63 "HG    T-REF= 102. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       271.     HZ     VOLUMETRIC FLOW RATE  11.81 GAL/HR
FUEL PRESSURE AT F/M   320.1    PSIA     FUEL TEMP AT F/M         92.  DEG F

                     ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     42.82 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               43.59 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  3.65  "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    2.107 %     O2   18.400 %     CO    466.0 PPM      CHX     32.0 PPM
 NO      8.4 PPM  NO2     12.3 PPM  NOX     20.8 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  41.82                 CHX=    4.52
                 CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=   3.06

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .010170
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.4995 %
   CHECK ON F/A RATIO= F/A = .010340 W/O O2, CALCULATED O2 = 18.826 %

SMOKE INDEX: 28.0
SALTZMAN NOX = 20.76              PPM         E.I. = 3.05
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Figure 377. Final Modified Conventional Liner, Modification "A" at Nonregenerative 10% Power - 32% Closed DZ.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING # 817
T3 MODIFIED CONVENTIONAL LINER, MOD "A" AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-19-72 READING WAS TAKEN AT 1028:13 HOURS

CYCLE POINT 1 VARIABLE GEOMETRY 50 % CLOSED 10 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW 1.863 LB/SEC AVG BURNER INLET TEMP 300. DEG F
AVG BURNER INLET PRES 44.6 PSIA AVG BURNER OUTLET TEMP 992. DEG F
AVG BURNER DELTA P 3.97 "HG PRESSURE LOSS 4.37 %
OVERALL F/A RATIO .01083 (F/M) FUEL FLOW RATE 73.42 LB/HR
AIR LOAD FACTOR 1.1627 PATTERN FACTOR .21547
BOT HOT SPOT: # 34 = 1142. DEG F MAX BOT / AVG BOT 1.1503
FUEL INLET TEMPERATURE 114. DEG F FUEL INLET PRESSURE 250.7 PSIA
HEAT LOADING PARAMETER .35652E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	994.	6	467.	15	1033.	19	879.	24	1043.	27	1077.	36	1107.
ANNULUS 2	4	1024.	7	1055.	16	1004.	21	895.	25	1060.	34	1142.	37	1126.
ANNULUS 3	5	1015.	14	1086.	17	935.	22	878.	26	972.	35	1007.	39	1043.

LEFT SIDE *** AIR INLET TUBE CONDITIONS *** RIGHT SIDE
TOTAL PRESSURE 44.63 PSIA TOTAL PRESSURE 44.66 PSIA
STATIC PRESSURE 44.41 PSIA STATIC PRESSURE 44.33 PSIA
VELOCITY DELTA P .45 "HG VELOCITY DELTA P .66 "HG
AIR TEMPERATURE 300. DEG F AIR TEMPERATURE 301. DEG F
AIR VELOCITY 113.57 FT/SEC AIR VELOCITY 138.67 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.055 "HG

AIR FLOW DATA: P-REF= 105.7 PSIA DELTA P= 1.65 "HG T-REF= 101. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY 272. HZ VOLUMETRIC FLOW RATE 11.05 GAL/HR
FUEL PRESSURE AT F/M 320.7 PSIA FUEL TEMP AT F/M 94. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 42.69 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 43.59 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 3.05 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 2.107 % O2 18.300 % CO 449.9 PPM CHX 25.8 PPM
NO 5.6 PPM NO2 12.3 PPM NOX 17.9 PPM [NO(NDIR) + NO2(NDUV)]
NO .0 PPM NO2 .0 PPM NOX .0 PPM [CHEMILUMINESCENCE]
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 40.59 CHX= 3.55
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 2.66

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .010200
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 98.6419 %
CHECK ON F/A RATIO- F/A = .010331 W/O O2, CALCULATED O2 = 18.028 %

SMOKE INDEX: 25.0
SALTZMAN NOX = 17.94 PPM E.I. = 2.67

Figure 378. Final Modified Conventional Liner, Modification "A" at Nonregenerative 10% Power - 50% Closed DZ.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING # 818
T63 MODIFIED CONVENTIONAL LINER, MOD "A" AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-19-72 READING WAS TAKEN AT 1904:33 HOURS

CYCLE POINT 6 VARIABLE GEOMETRY 32 % CLOSED 25 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.194 LB/SEC	AVG BURNER INLET TEMP	352. DEG F
AVG BURNER INLET PRES	54.7 PSIA	AVG BURNER OUTLET TEMP	1102. DEG F
AVG BURNER DELTA P	3.62 "HG	PRESSURE LOSS	3.26 %
OVERALL F/A RATIO	.01212 (F/M)	FUEL FLOW RATE	95.70 LB/HR
AIR LOAD FACTOR	1.1434	PATTERN FACTOR	.41127
BOT HOT SPOT: # 34 = 1410.	DEG F	MAX BOT / AVG BOT	1.2799
FUEL INLET TEMPERATURE 116.	DEG F	FUEL INLET PRESSURE	304.6 PSIA

HEAT LOADING PARAMETER .37951E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	943.	6	152.	15	1189.	19	848.	24	1156.	27	1296.	36	1237.
ANNULUS 2	4	1104.	7	1307.	16	1125.	21	889.	25	1286.	34	1410.	37	1224.
ANNULUS 3	5	1187.	14	1274.	17	967.	22	944.	26	1332.	35	1260.	39	995.

*** AIR INLET TUBE CONDITIONS ***

LEFT SIDE		RIGHT SIDE	
TOTAL PRESSURE	54.66 PSIA	TOTAL PRESSURE	54.67 PSIA
STATIC PRESSURE	54.39 PSIA	STATIC PRESSURE	54.37 PSIA
VELOCITY DELTA P	.54 "HG	VELOCITY DELTA P	.61 "HG
AIR TEMPERATURE	351. DEG F	AIR TEMPERATURE	352. DEG F
AIR VELOCITY	116.49 FT/SEC	AIR VELOCITY	124.36 FT/SEC

DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.022 "HG

AIR FLOW DATA: P-REF= 105.0 PSIA DELTA P= 2.24 "HG T-REF= 98. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	354. HZ	VOLUMETRIC FLOW RATE	15.47 GAL/HR
FUEL PRESSURE AT F/M	367.1 PSIA	FUEL TEMP AT F/M	96. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 52.88 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 53.59 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 3.61 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 2.254 % O2 18.200 % CO 349.5 PPM CHX 7.3 PPM
NO 16.9 PPM NO2 11.5 PPM NOX 28.4 PPM [NO(NDIR) + NO2(NDUV)]
NO .0 PPM NO2 .0 PPM NOX .0 PPM [CHEMILUMINESCENCE]
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 28.23 CHX= .93
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 3.76

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .010765
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.1730 %
CHECK ON F/A RATIO- F/A = .010952 W/O O2, CALCULATED O2 = 17.831 %

SMOKE INDEX: 53.0
SALTZMAN NOX = 25.59 PPM E.I. = 3.39

Figure 379. Final Modified Conventional Liner, Modification "A" at Nonregenerative 25% Power - 32% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    819
T63 MODIFIED CONVENTIONAL LINER, MOD "A" AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-19-72                     READING WAS TAKEN AT 1926: 9 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  32 % CLOSED       40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         2.564 LB/SEC    AVG BURNER INLET TEMP   398. DEG F
AVG BURNER INLET PRES  64.2    PSIA     AVG BURNER OUTLET TEMP 1209. DEG F
AVG BURNER DELTA P      4.15    "HG     PRESSURE LOSS             3.17 %
OVERALL F/A RATIO     .01296   (F/M)    FUEL FLOW RATE          119.61 LB/HR
AIR LOAD FACTOR        1.1702           PATTERN FACTOR           .34719
BOT HOT SPOT: # 34 = 1490.  DEG F       MAX BOT / AVG BOT       1.2327
FUEL INLET TEMPERATURE 110.  DEG F      FUEL INLET PRESSURE      329.5  PSIA
HEAT LOADING PARAMETER  .40393E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1047.  6  208. 15 1283. 19  928. 24 1257. 27 1425. 36 1365.
ANNULUS 2   4 1205.  7 1418. 16 1243. 21  971. 25 1403. 34 1490. 37 1364.
ANNULUS 3   5 1291. 14 1375. 17 1078. 22 1046. 26 1448. 35 1412. 39 1130.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           64.14    PSIA   TOTAL PRESSURE          64.24   PSIA
STATIC PRESSURE          63.84    PSIA   STATIC PRESSURE         63.97   PSIA
VELOCITY DELTA P           .62     "HG   VELOCITY DELTA P          .55    "HG
AIR TEMPERATURE           398.   DEG F   AIR TEMPERATURE          399.  DEG F
AIR VELOCITY            118.58 FT/SEC    AIR VELOCITY           111.32 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]           -.192    "HG

AIR FLOW DATA: P-REF= 104.9 PSIA   DELTA P= 3.06 "HG    T-REF=  95. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       442.      HZ     VOLUMETRIC FLOW RATE  19.35 GAL/HR
FUEL PRESSURE AT F/M   438.1     PSIA     FUEL TEMP AT F/M        98.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    62.15 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             62.87 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.05  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.500 %     O2   17.700 %     CO    267.9 PPM     CHX     3.1 PPM
 NO     23.2 PPM  NO2     13.3 PPM  NOX     36.5 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  20.25                 CHX=     .37
                   CHEMILUMINESCENCE NOX=     .00,   NDIR + NDUV NOX=    4.53

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011958
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.4520 %
   CHECK ON F/A RATIO- F/A = .012073 W/O O2, CALCULATED O2 = 17.494 %

SMOKE INDEX: 59.0
SALTZMAN NOX = 32.10                 PPM        E.I. = 3.98
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Figure 380. Final Modified Conventional Liner, Modification "A" at Nonregenerative 40% Power - 32% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    828
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-19-72                        READING WAS TAKEN AT 1944:45 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  50 % CLOSED       40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         2.519 LB/SEC     AVG BURNER INLET TEMP    398. DEG F
AVG BURNER INLET PRES  63.8    PSIA      AVG BURNER OUTLET TEMP 1286. DEG F
AVG BURNER DELTA P      4.72    "HG      PRESSURE LOSS             3.63 %
OVERALL F/A RATIO      .01309  (F/M)     FUEL FLOW RATE          118.73 LB/HR
AIR LOAD FACTOR        1.1573            PATTERN FACTOR          .30322
BOT HOT SPOT: # 26 = 1451.  DEG F        MAX BOT / AVG BOT       1.2831
FUEL INLET TEMPERATURE 105.  DEG F       FUEL INLET PRESSURE      339.2  PSIA
HEAT LOADING PARAMETER  .40367E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1109.  6  222. 15 1233. 19 1005. 24 1259. 27 1376. 36 1302.
ANNULUS 2   4 1224.  7 1405. 16 1224. 21 1085. 25 1357. 34 1415. 37 1342.
ANNULUS 3   5 1269. 14 1290. 17 1111. 22 1162. 26 1451. 35 1284. 39 1192.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE         63.75    PSIA     TOTAL PRESSURE          63.77   PSIA
STATIC PRESSURE        63.39    PSIA     STATIC PRESSURE         63.50   PSIA
VELOCITY DELTA P         .72    "HG      VELOCITY DELTA P          .56   "HG
AIR TEMPERATURE         398.  DEG F      AIR TEMPERATURE          398.  DEG F
AIR VELOCITY          128.15 FT/SEC      AIR VELOCITY           112.55 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.044    "HG

AIR FLOW DATA: P-REF= 104.1 PSIA   DELTA P= 2.07 "HG    T-REF=  93. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      439.      HZ     VOLUMETRIC FLOW RATE  19.22 GAL/HR
FUEL PRESSURE AT F/M  445.1     PSIA     FUEL TEMP AT F/M         99.   DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    61.44 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             62.38 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.69  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.575 %     O2  17.400 %     CO    267.9 PPM     CHX      2.1 PPM
 NO     26.7 PPM   NO2      9.7 PPM  NOX    36.5 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  20.85                 CHX=     .25
                  CHEMILUMINESCENCE NOX=     .00,     NDIR + NDUV NOX=   4.40

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .012418
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.4793 %
   CHECK ON F/A RATIO- F/A = .012424 W/O O2, CALCULATED O2 = 17.391 %

SMOKE INDEX: 54.0
SALTZMAN NOX = 32.31                PPM         E.I. = 3.97
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Figure 381. Final Modified Conventional Liner, Modification "A" at Nonregenerative 40% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    021
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-19-72                         READING WAS TAKEN AT 2007:43 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  70 % CLOSED        40 % POWER SETTING

                 ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.548 LB/SEC    AVG BURNER INLET TEMP    397. DEG F
AVG BURNER INLET PRES   63.8    PSIA     AVG BURNER OUTLET TEMP 1212. DEG F
AVG BURNER DELTA P       4.98    "HG     PRESSURE LOSS             3.83 %
OVERALL F/A RATIO      .01308  (F/W)     FUEL FLOW RATE          119.99 LB/HR
AIR LOAD FACTOR        1.1687            PATTERN FACTOR          .24251
BOT HOT SPOT:  # 26 = 1409.  DEG F       MAX BOT / AVG BOT       1.1630
FUEL INLET TEMPERATURE 108.  DEG F       FUEL INLET PRESSURE     337.7  PSIA
HEAT LOADING PARAMETER  .40757E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1006.  6  204. 15 1251. 19 1014. 24 1299  27 1309. 36 1305.
ANNULUS 2   4 1198.  7 1332. 16 1232. 21 1149. 25 1399. 34 1385. 37 1342.
ANNULUS 3   5 1221. 14 1331. 17 1109. 22 1250. 26 1409. 35 1365. 39 1167.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE           63.79    PSIA   TOTAL PRESSURE          63.85   PSIA
STATIC PRESSURE          63.35    PSIA   STATIC PRESSURE         63.55   PSIA
VELOCITY DELTA P           .89    "HG    VELOCITY DELTA P          .61   "HG
AIR TEMPERATURE          397.  DEG F     AIR TEMPERATURE         398.  DEG F
AIR VELOCITY            142.79 FT/SEC    AIR VELOCITY           118.26 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.129   "HG

AIR FLOW DATA: P-REF= 104.4 PSIA   DELTA P= 3.01 "HG   T-REF=  91. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       444.      HZ    VOLUMETRIC FLOW RATE  16.44 GAL/HR
FUEL PRESSURE AT F/M   454.8     PSIA    FUEL TEMP AT F/M        100.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   61.30 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            62.26 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               4.91  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2    2.575 %     O2  17.600 %      CO   201.3 PPM     CHX      2.0 PPM
 NO     23.2 PPM   NO2     16.1 PPM  NOX    39.4 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM   NO2       .0 PPM  NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  21.07                  CHX=     .34
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    4.04

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .012300
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  00.4402 %
   CHECK ON F/A RATIO- F/A = .012431 W/O O2, CALCULATED O2 = 17.300 %

SMOKE INDEX: 53.0
SALTZMAN NOX = 31.50                 PPM        E.I. = 3.87
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Figure 382. Final Modified Conventional Liner, Modification "A" at Nonregenerative 40% Power - 72% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    022
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-20-72                        READING WAS TAKEN AT 1122:12 HOURS

CYCLE POINT  4    VARIABLE GEOMETRY  32 % CLOSED       55 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.737 LB/SEC    AVG BURNER INLET TEMP   430. DEG F
AVG BURNER INLET PRES  71.2   PSIA       AVG BURNER OUTLET TEMP 1374. DEG F
AVG BURNER DELTA P      4.79   "HG       PRESSURE LOSS             3.31 %
OVERALL F/A RATIO      .01454  (F/M)     FUEL FLOW RATE          143.20 LB/HR
AIR LOAD FACTOR        1.1464            PATTERN FACTOR           .30117
BOT HOT SPOT:  # 26 = 1658.   DEG F      MAX BOT / AVG BOT       1.2070
FUEL INLET TEMPERATURE 100.   DEG F      FUEL INLET PRESSURE      431.0   PSIA
HEAT LOADING PARAMETER   .43629E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1091.  6 1370. 15 1425. 19 1004. 24 1373. 27 1556. 36 1480.
ANNULUS 2   4 1202.  7 1487. 16 1391. 21 1072. 25 1544. 34 1637. 37 1000.
ANNULUS 3   5 1315. 14 1540. 17 1248. 22 1160. 26 1658. 35 1459. 39 1260.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          71.18    PSIA    TOTAL PRESSURE          71.21   PSIA
STATIC PRESSURE         70.88    PSIA    STATIC PRESSURE         70.87   PSIA
VELOCITY DELTA P          .60    "HG     VELOCITY DELTA P          .79   "HG
AIR TEMPERATURE          429.  DEG F     AIR TEMPERATURE          430.  DEG F
AIR VELOCITY           112.90 FT/SEC     AIR VELOCITY           122.16 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.073    "HG

AIR FLOW DATA: P-REF= 103.5 PSIA   DELTA P= 3.61 "HG   T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      529.      HZ     VOLUMETRIC FLOW RATE  23.16 GAL/HR
FUEL PRESSURE AT F/M  530.4    PSIA      FUEL TEMP AT F/M          86.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   68.84 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               69.02 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  4.76  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.751 %     O2  14.500 %     CO    220.1 PPM     CHX      1.0 PPM
 NO     33.7 PPM  NO2      .0 PPM  NOX     33.7 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2      .0 PPM  NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  15.33                    CHX=    .10
                   CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   3.74

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .010112
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8003 %
   CHECK ON F/A RATIO- F/A = .013230 W/O O2, CALCULATED O2 = 17.151 %

SMOKE INDEX: 63.29
SALTZMAN NOX = 39.9                PPM          G.I. = 4.43
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Figure 383. Final Modified Conventional Liner, Modification "A" at Nonregenerative 55% Power - 32% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #     023
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS,
TEST DATE: 7-20-72                          READING WAS TAKEN AT 113956 HOURS

CYCLE POINT  4    VARIABLE GEOMETRY  50 % CLOSED       55 % POWER SETTING

                      ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW           2.747 LB/SEC     AVG BURNER INLET TEMP   431. DEG F
AVG BURNER INLET PRES  71.2    PSIA     AVG BURNER OUTLET TEMP 1387. DEG F
AVG BURNER DELTA P       5.70    "HG      PRESSURE LOSS               3.90 %
OVERALL F/A RATIO      .01442  (F/P)    FUEL FLOW RATE           142.55 LB/HR
AIR LOAD FACTOR         1.1507           PATTERN FACTOR            .20638
BOT HOT SPOT:  # 34 = 1584.   DEG F     MAX BOT / AVG BOT         1.1423
FUEL INLET TEMPERATURE  97.   DEG F     FUEL INLET PRESSURE      420.7   PSIA
HEAT LOADING PARAMETER  .43379E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1254.   6 1388. 15 1304. 19 1169. 24 1452. 27 1533. 36 1485.
ANNULUS 2   4 1270.   7 1405. 16 1371. 21 1231. 25 1539. 34 1584. 37 1493.
ANNULUS 3   5 1286. 14 1438. 17 1259. 22 1204. 26 1502. 35 1514. 39 1351.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           71.21    PSIA    TOTAL PRESSURE           71.26    PSIA
STATIC PRESSURE          70.88    PSIA    STATIC PRESSURE          70.86    PSIA
VELOCITY DELTA P           .60    "HG     VELOCITY DELTA P           .81    "HG
AIR TEMPERATURE           430.  DEG F     AIR TEMPERATURE           431.  DEG F
AIR VELOCITY            119.07 FT/SEC     AIR VELOCITY            131.28 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))    -.094    "HG

AIR FLOW DATA: P-REF= 103.4 PSIA   DELTA P= 3.65 "HG   T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       527.      HZ     VOLUMETRIC FLOW RATE  23.07 GAL/HR
FUEL PRESSURE AT F/M   575.7    PSIA     FUEL TEMP AT F/M          98.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    68.40 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              69.73 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 5.73 "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    3.004 %     O2  14.200 %      CO    240.0 PPM      CHX       .0 PPM
 NO     27.4 PPM  NO2       .0 PPM  NOX     27.4 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  16.07                     CHX=    .00
                 CHEMILUMINESCENCE NOX=     .00,   NDIR + NDUV NOX=   3.07

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .016430
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  90.0030 %
   CHECK ON F/A RATIO- F/A = .014420 W/O O2, CALCULATED O2 = 16.707 %

SMOKE INDEX: 56.59
SALTZMAN NOX = 44.5                 PPM   E.I. = 4.99
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Figure 384. Final Modified Conventional Liner, Modification "A" at Nonregenerative 55% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    024
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE:  7-20-72                       READING WAS TAKEN AT 120313S HOURS

CYCLE POINT  4    VARIABLE GEOMETRY  70 % CLOSED       55 % POWER SETTING

                       ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.710 LB/SEC     AVG BURNER INLET TEMP   430. DEG F
AVG BURNER INLET PRES  71.4    PSIA      AVG BURNER OUTLET TEMP 1304. DEG F
AVG BURNER DELTA P      6.47    "HG      PRESSURE LOSS             4.45 %
OVERALL F/A RATIO     .01462  (F/M)      FUEL FLOW RATE          142.61 LB/HR
AIR LOAD FACTOR        1.1315            PATTERN FACTOR          .34003
BOT HOT SPOT:  # 34 = 1731.  DEG F       MAX BOT / AVG BOT       1.2413
FUEL INLET TEMPERATURE 104.  DEG F       FUEL INLET PRESSURE      436.7  PSIA
HEAT LOADING PARAMETER  .43274E+07 BTU/HOUR/ATM/CUBIC FOOT

                      **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1273.  6 1263. 15 1354. 19 1183. 24 1537. 27 1492. 36 1564.
ANNULUS 2   4 1272.  7 1245. 16 1342. 21 1229. 25 1501. 34 1731. 37 1500.
ANNULUS 3   5 1215. 14 1414. 17 1273. 22 1300. 26 1493. 35 1500. 39 1420.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE            71.44   PSIA    TOTAL PRESSURE           71.44   PSIA
STATIC PRESSURE           71.03   PSIA    STATIC PRESSURE          71.14   PSIA
VELOCITY DELTA P           .85     "HG    VELOCITY DELTA P           .60    "HG
AIR TEMPERATURE           430.  DEG F     AIR TEMPERATURE           430.  DEG F
AIR VELOCITY            133.82 FT/SEC     AIR VELOCITY            112.77 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]             .017    "HG

AIR FLOW DATA: P-REF= 103.0 PSIA   DELTA P= 3.80 "HG   T-REF= 110. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       520.      HZ     VOLUMETRIC FLOW RATE  23.11 GAL/HR
FUEL PRESSURE AT F/M  505.0    PSIA      FUEL TEMP AT F/M         101.  DEG F

                    ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   68.26 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             69.67 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.40  "HG (XDUCER # 13)

                        * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    3.106 %      O2  13.000 %     CO    237.6 PPM      CHX      1.4 PPM
 NO     28.1 PPM  NO2       .0 PPM  NOX     28.1 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  15.90                   CHX=    .10
                   CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   3.10

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .017117
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  30.0200 %
   CHECK ON F/A RATIO- F/A = .014006 W/O O2, CALCULATED O2 = 16.056 %

SMOKE INDEX: 49.63
SALTZMAN NOX = 43.9                PPM          E.I. = 4.84
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Figure 385. Final Modified Conventional Liner, Modification "A" at Nonregenerative 55% Power - 70% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    825
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE:  7-28-72                    READING WAS TAKEN AT 12:32:41 HOURS

CYCLE POINT  3    VARIABLE GEOMETRY  50 % CLOSED      75 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.966 LB/SEC    AVG BURNER INLET TEMP   473. DEG F
AVG BURNER INLET PRES  80.8    PSIA      AVG BURNER OUTLET TEMP 1568. DEG F
AVG BURNER DELTA P      6.22    "HG      PRESSURE LOSS            3.70 %
OVERALL F/A RATIO      .01667  (F/M)     FUEL FLOW RATE         177.96 LB/HR
AIR LOAD FACTOR        1.1215            PATTERN FACTOR          .21583
BOT HOT SPOT:  # 26 = 1805.  DEG F       MAX BOT / AVG BOT      1.1507
FUEL INLET TEMPERATURE 111.  DEG F       FUEL INLET PRESSURE    515.0  PSIA
HEAT LOADING PARAMETER  .47747E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1430.  6 1584. 15 1561. 19 1318. 24 1592. 27 1688. 36 1584.
ANNULUS 2   4 1520.  7 1602. 16 1558. 21 1377. 25 1711. 34 1714. 37 1628.
ANNULUS 3   5 1510. 14 1669. 17 1462. 22 1422. 26 1805. 35 1693. 39 1549.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           80.79   PSIA    TOTAL PRESSURE        80.80   PSIA
STATIC PRESSURE          80.35   PSIA    STATIC PRESSURE       80.39   PSIA
VELOCITY DELTA P           .09    "HG    VELOCITY DELTA P        .08    "HG
AIR TEMPERATURE           473.  DEG F    AIR TEMPERATURE        474.  DEG F
AIR VELOCITY            132.27 FT/SEC    AIR VELOCITY         128.01 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))        -.030    "HG

AIR FLOW DATA: P-REF= 102.5 PSIA   DELTA P= 4.33 "HG   T-REF= 111. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       602.     HZ     VOLUMETRIC FLOW RATE  26.80 GAL/HR
FUEL PRESSURE AT F/M   584.5   PSIA      FUEL TEMP AT F/M        104.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    77.74 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             79.04 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.21  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    3.313 %     O2  16.750 %     CO   107.7 PPM     CHX       .0 PPM
 NO     42.9 PPM  NO2       .0 PPM  NOX   42.9 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX     .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.07                 CHX=    .05
                 CHEMILUMINESCENCE NOX=     .00,   NDIR + NDUV NOX=   4.10

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .015872
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7181 %
   CHECK ON F/A RATIO- F/A = .015848 W/O O2, CALCULATED O2 = 16.372 %

SMOKE INDEX: 63.74
SALTZMAN NOX = 51.3              PPM  E.I. = 4.97
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Figure 386. Final Modified Conventional Liner, Modification "A" at Nonregenerative 75% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    026
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE:  7-2?  2                          READING WAS TAKEN AT 1252:40 HOURS

CYCLE POINT  3    VARIABLE GEOMETRY  32 % CLOSED       75 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          3.036 LB/SEC     AVG BURNER INLET TEMP   471. DEG F
AVG BURNER INLET PRES   80.7    PSIA      AVG BURNER OUTLET TEMP 1530. DEG F
AVG BURNER DELTA P       5.39    "HG      PRESSURE LOSS            3.2? %
OVERALL F/A RATIO       .01624  (F/P)     FUEL FLOW RATE         177.58 LB/HR
AIR LOAD FACTOR         1.1478            PATTERN FACTOR          .34257
BOT HOT SPOT:  # 26 = 1892.  DEG F        MAX BOT / AVG BOT       1.2371
FUEL INLET TEMPERATURE 123.  DEG F        FUEL INLET PRESSURE     500.0  PSIA
HEAT LOADING PARAMETER  .47695E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1236.  6 1501. 10 1531. 19 1160. 24 1535. 27 1715. 30 1604.
ANNULUS 2   4 1303.  7 1600. 16 1540. 21 1100. 25 1730. 34 1630. 37 1645.
ANNULUS 3   5 1467. 14 1609. 17 1335. 22 1299. 26 1892. 35 1640. 39 1474.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE           80.65    PSIA    TOTAL PRESSURE           80.70   PSIA
STATIC PRESSURE          80.17    PSIA    STATIC PRESSURE          80.40   PSIA
VELOCITY DELTA P           .90    "HG     VELOCITY DELTA P           .61    "HG
AIR TEMPERATURE          470.  DEG F      AIR TEMPERATURE          471.  DEG F
AIR VELOCITY            130.14 FT/SEC     AIR VELOCITY            100.83 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.000    "HG

AIR FLOW DATA: P-REF= 102.9 PSIA   DELTA P= 4.83 "HG   T-REF= 119. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       601.     HZ      VOLUMETRIC FLOW RATE  26.69 GAL/HR
FUEL PRESSURE AT F/M   653.6     PSIA     FUEL TEMP AT F/M         106.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     78.03 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              79.23 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 5.34  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    3.004 %     O2  16.000 %     CO    103.4 PPM     CHX       .0 PPM
 NO     40.0 PPM  NO2       .0 PPM  NOX    40.0 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  11.10                    CHX=    .07
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    4.08

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .014333
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  00.0000 %
   CHECK ON F/A RATIO- F/A = .014399 W/O O2, CALCULATED O2 = 16.0?2 %

SMOKE INDEX:  69.05
SALTZMAN NOX = 51.7                PPM    E.I.: 5.13
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Figure 387. Final Modified Conventional Liner, Modification "A", at Nonregenerative 75% Power - 32% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    027
T63 MODIFIED CONVENTIONAL LINER, MOD "A"  AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-20-72                      READING WAS TAKEN AT 1319: 1 HOURS

CYCLE POINT  2    VARIABLE GEOMETRY  32 % CLOSED      100 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          3.233 LB/SEC    AVG BURNER INLET TEMP   522. DEG F
AVG BURNER INLET PRES   91.0    PSIA     AVG BURNER OUTLET TEMP 1748. DEG F
AVG BURNER DELTA P       5.59    "HG     PRESSURE LOSS            3.02 %
OVERALL F/A RATIO      .01946  (F/M)     FUEL FLOW RATE         226.52 LB/HR
AIR LOAD FACTOR         1.1131           PATTERN FACTOR          .33050
BOT HOT SPOT:  # 26 = 2153.  DEG F       MAX BOT / AVG BOT      1.2310
FUEL INLET TEMPERATURE 119.  DEG F       FUEL INLET PRESSURE     662.2  PSIA
HEAT LOADING PARAMETER  .53967E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1480.  6 1754. 15 1765. 19 1400. 24 1772. 27 1859. 36 1742.
ANNULUS 2   4 1579.  7 1944. 16 1755. 21 1453. 25 1970. 34 2013. 37 1773.
ANNULUS 3   5 1662. 14 1875. 17 1619. 22 1592. 26 2153. 35 1947. 39 1502.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           91.00   PSIA    TOTAL PRESSURE          90.90   PSIA
STATIC PRESSURE          90.60   PSIA    STATIC PRESSURE         90.45   PSIA
VELOCITY DELTA P          .65    "HG     VELOCITY DELTA P         1.00   "HG
AIR TEMPERATURE          521.  DEG F     AIR TEMPERATURE          522.  DEG F
AIR VELOCITY            109.09 FT/SEC    AIR VELOCITY           140.40 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          .032    "HG

AIR FLOW DATA: P-REF= 102.4 PSIA   DELTA P= 5.10 "HG   T-REF= 113. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       840.      HZ    VOLUMETRIC FLOW RATE  36.00 GAL/HR
FUEL PRESSURE AT F/M   663.0    PSIA     FUEL TEMP AT F/M         150.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   88.24 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             89.45 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.61  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   3.004 %      O2  15.000 %     CO    123.7 PPM     CHX       .0 PPM
 NO     78.6 PPM   NO2       .0 PPM  NOX    78.6 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   6.26                   CHX=    .00
                    CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   6.54

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .018320
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8230 %
   CHECK ON F/A RATIO- F/A = .018928 W/O O2, CALCULATED O2 = 15.807 %

SMOKE INDEX:  75.16
SALTZMAN NOX = 760                 PPM     E.I. = 6.32
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Figure 388. Final Modified Conventional Liner, Modification "A", at Nonregenerative 100% Power - 32% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 59, TEST SERIES 69, READING #    828
T63 MODIFIED CONVENTIONAL LINER, MOD "A" AT STD. T63 INLET CONDITIONS.
TEST DATE: 7-20-72                      READING WAS TAKEN AT 1339121 HOURS

CYCLE POINT  2    VARIABLE GEOMETRY  50 % CLOSED      100 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         3.187 LB/SEC     AVG BURNER INLET TEMP    524. DEG F
AVG BURNER INLET PRES  91.2   PSIA       AVG BURNER OUTLET TEMP 1760. DEG F
AVG BURNER DELTA P      7.14   "HG       PRESSURE LOSS             3.85 %
OVERALL F/A RATIO      .01928  (F/M)     FUEL FLOW RATE          221.22 LB/HR
AIR LOAD FACTOR        1.0969            PATTERN FACTOR          .34319
BOT HOT SPOT:  # 34 = 2184.  DEG F       MAX BOT / AVG BOT       1.2410
FUEL INLET TEMPERATURE 136.  DEG F       FUEL INLET PRESSURE       .0  PSIA
HEAT LOADING PARAMETER  .526[illegible]+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
              ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1609.  6 16[illegible]. 15 1690. 19 1401. 24 1729. 27 1935. 36 1924.
ANNULUS 2   4 1634.  7 1720. 16 1667. 21 1484. 25 1872. 34 2184. 37 1969.
ANNULUS 3   5 1610. 14 1787. 17 1510. 22 1510. 26 2030. 35 2181. 39 1838.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          91.12   PSIA     TOTAL PRESSURE          91.10   PSIA
STATIC PRESSURE         90.68   PSIA     STATIC PRESSURE         90.81   PSIA
VELOCITY DELTA P          .91    "HG     VELOCITY DELTA P          .74    "HG
AIR TEMPERATURE          523.  DEG F     AIR TEMPERATURE          525.  DEG F
AIR VELOCITY           128.64 FT/SEC     AIR VELOCITY           116.55 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.118    "HG

AIR FLOW DATA: P-REF= 102.3 PSIA   DELTA P= 5.04 "HG    T-REF= 114. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       830.      HZ    VOLUMETRIC FLOW RATE  36.06 GAL/HR
FUEL PRESSURE AT F/M   674.1    PSIA     FUEL TEMP AT F/M        111.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    87.64 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             89.07 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.08  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    3.840 %      O2  15.700 %      CO    108.6 PPM     CHX      .1 PPM
 NO     69.6 PPM  NO2        .0 PPM  NOX    69.6 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2        .0 PPM  NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    5.55                  CHX=    .01
                 CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=   5.84

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .018223
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8420 %
   CHECK ON F/A RATIO- F/A = .018271 W/O O2, CALCULATED O2 = 15.644 %

SMOKE INDEX: 65.49
SALTZMAN NOX = 62.3               PPM          E.I. = 5.23
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Figure 389. Final Modified Conventional Liner, Modification "A", at Nonregenerative 100% Power - 50% Closed DZ.

TABLE LXXXIV. COMBUSTOR PERFORMANCE STANDARD-LENGTH, MODIFIED CONVENTIONAL FINAL DESIGN, MODIFICATION "A"

DUTY CYCLE POINT	1	6	5	4	3	2
32% Closed						
CO, (ppm)	466.0	349.5	267.9	228.1	183.4	123.7
H/C, (ppm)	32.0	7.3	3.1	1.8	.8	.0
NO_x (NDIR + NDUV)(ppm)	20.8	28.4	36.5	--	--	--
NO_x (Saltzman)(ppm)	20.8	25.6	32.1	39.9	51.7	76.0
Smoke Number	28.0	53.0	59.0	63.3	69.0	75.2
Pressure Loss, %	4.03	3.26	3.17	3.31	3.28	3.02
T_{max}/T_{avg}	1.259	1.280	1.233	1.207	1.237	1.232
50% Closed						
CO, (ppm)	449.9		267.9	245.0	187.7	108.6
H/C, (ppm)	25.0		2.1	.8	.5	.1
NO_x (NDIR + NDUV)(ppm)	17.9		36.5	--	--	--
NO_x (Saltzman)(ppm)	17.9		32.3	44.5	51.3	62.3
Smoke Number	25.0		54.0	56.6	63.7	65.5
Pressure Loss, %	4.37		3.63	3.98	3.78	3.85
T_{max}/T_{avg}	1.150		1.203	1.142	1.151	1.241
70% Closed						
CO, (ppm)			281.3	237.6		
H/C, (ppm)			2.9	1.4		
NO_x (NDIR + NDUV)(ppm)			39.4	--		
NO_x (Saltzman)(ppm)			31.5	43.9		
Smoke Number			53.0	49.6		
Pressure Loss, %			3.83	4.45		
T_{max}/T_{avg}			1.163	1.241		

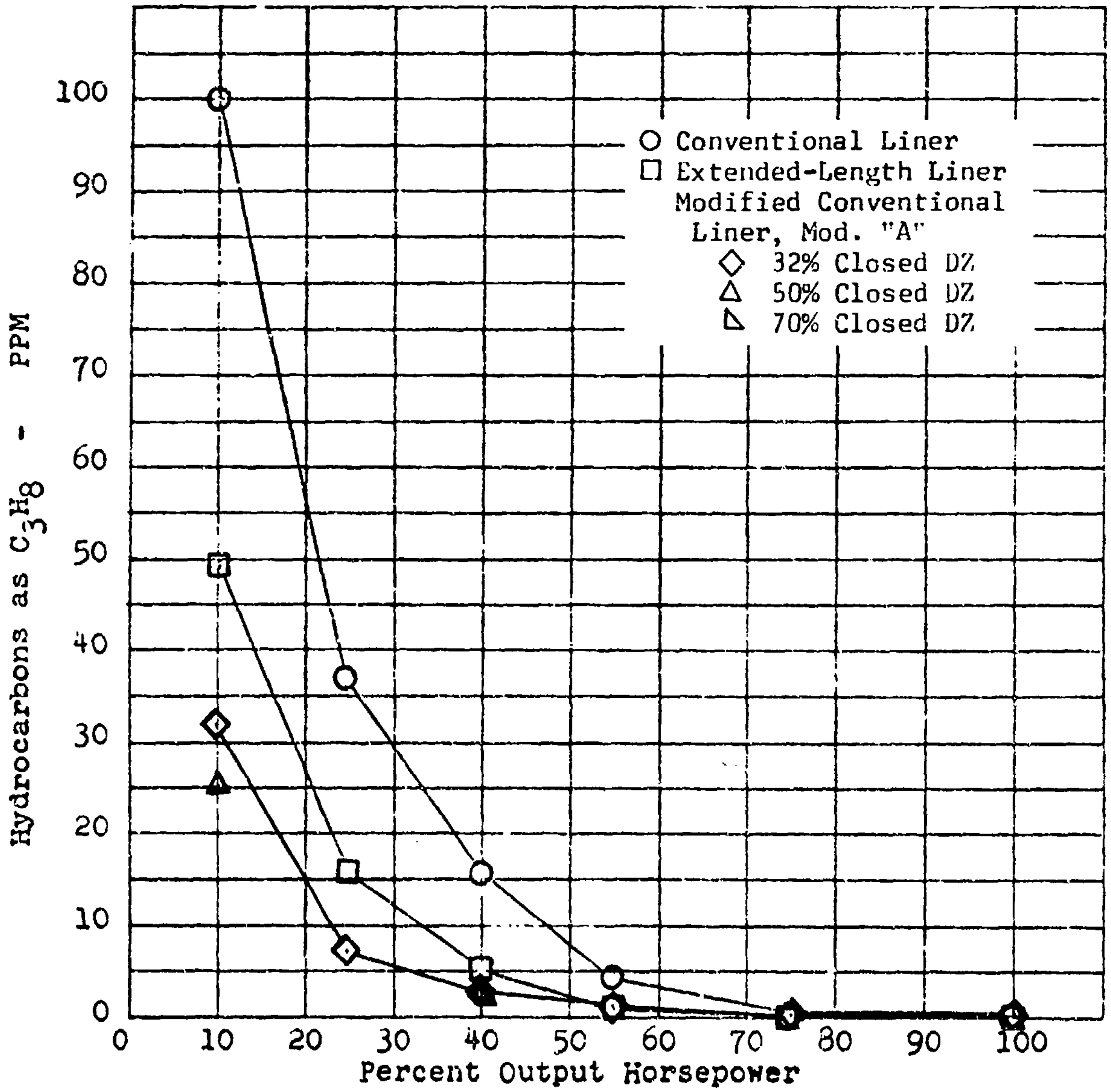

Figure 390. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Standard-Length, Modified Conventional Design Modification "A" Combustor and T63 Baseline Combustors.

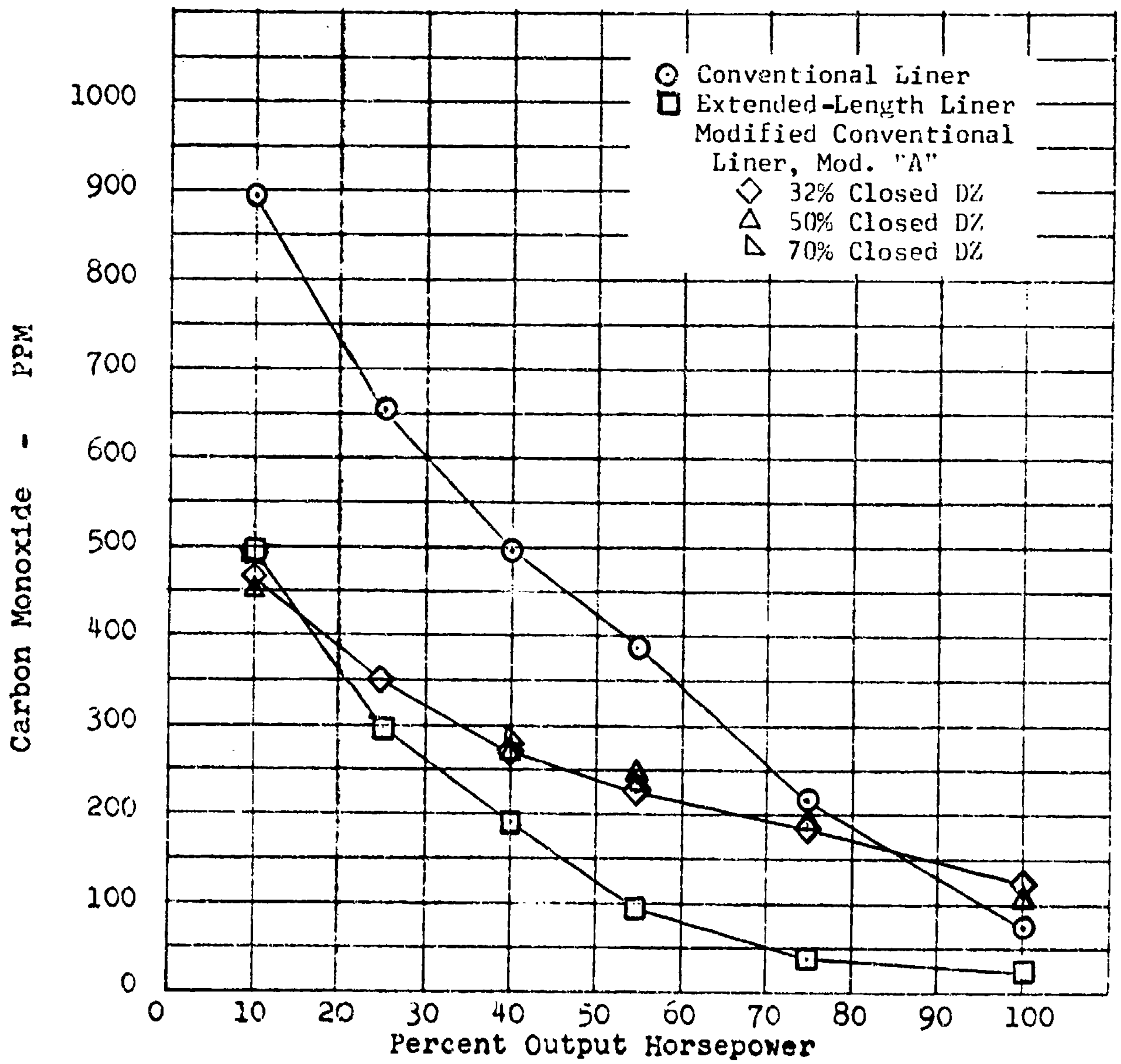

Figure 391. Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Standard-Length, Modified Conventional Design Modification "A" Combustor and T63 Baseline Combustors.

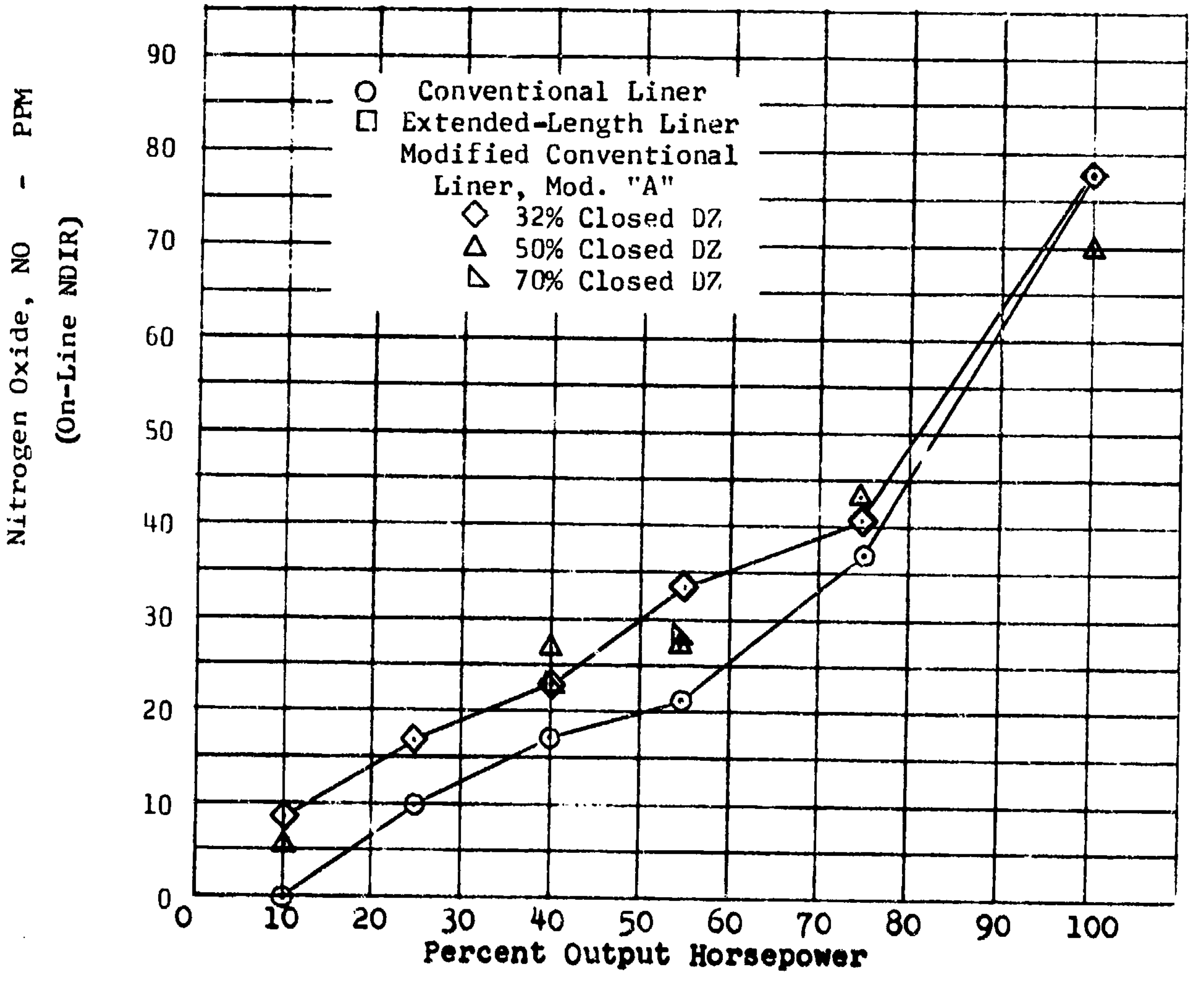

Figure 392. Nonregenerative T63-A-5A Combustor Nitrogen Oxide Emission Data Comparison for Standard-Length, Modified Conventional, Final Design Modification "A" Combustor and T63 Baseline Combustors.

for NO_x measurements at cycle points 2, 3, and 4 during the test. Even though the NO constituents appeared to be higher for Modification "A", the comparison of the Saltzman measured NO_x indicated a reduction in NO_x of 13%. Smoke and particulates from Modification "A" were the highest from any of the Final Combustor configurations. As indicated in Figure 393, smoke numbers for all data points except idle (10% power) were 50 or higher. Only the 32% closed setting values are indicated in the figure, as the 50% and 70% values were also well above the ordinate scale.

The exhaust temperature profiles shown in Figure 394 indicate that there was general improvement when the dilution holes were closed from 32% to 50%. The 32% closed setting profile was unacceptably high, and the 50% closed profile was marginal. At idle combustor conditions, the dilution geometry was opened to the 0% closed position for a few minutes. The T_{max}/T_{avg} temperature profile was approximately 1.50, and the pressure loss was 3.4%. Because of the extremely poor idle profile, additional 0% closed settings were not used during the test. The skin thermocouple temperatures are plotted in Figures 395, 396, and 397 for the three geometry settings.

A lampblack flow visualization plate was made of the internal aerodynamics of the Modification "A" combustor liner as shown in Figure 398. The flow trace was obtained at the 32% closed dilution setting as indicated by the liner in the photograph. It appeared from the flow pattern that there was insufficient primary and dilution air penetration into the combustor, and thus the mixing and recirculation were ineffective.

The mechanical problems encountered with the variable-geometry band and the low pressure loss of the combustor were cited as the factors responsible for the poor combustor performance. Moving the dilution holes 2.00 inches upstream did not improve the exhaust temperature profile. The region of the combustor having the greatest influence on exhaust temperature profile must therefore be the primary zone, not the dilution zone.

<u>Modification "B"</u>

The design changes to Modification "A" of the Final Modified Conventional combustor which resulted in Modification "B" were the following:

- A new variable-geometry slip band was fabricated which would operate more smoothly and would leak less.

- The cantelevered actuator tabs connecting the actuator rods to the slip band were redesigned to increase their stiffness, thus eliminating any deformation during testing.

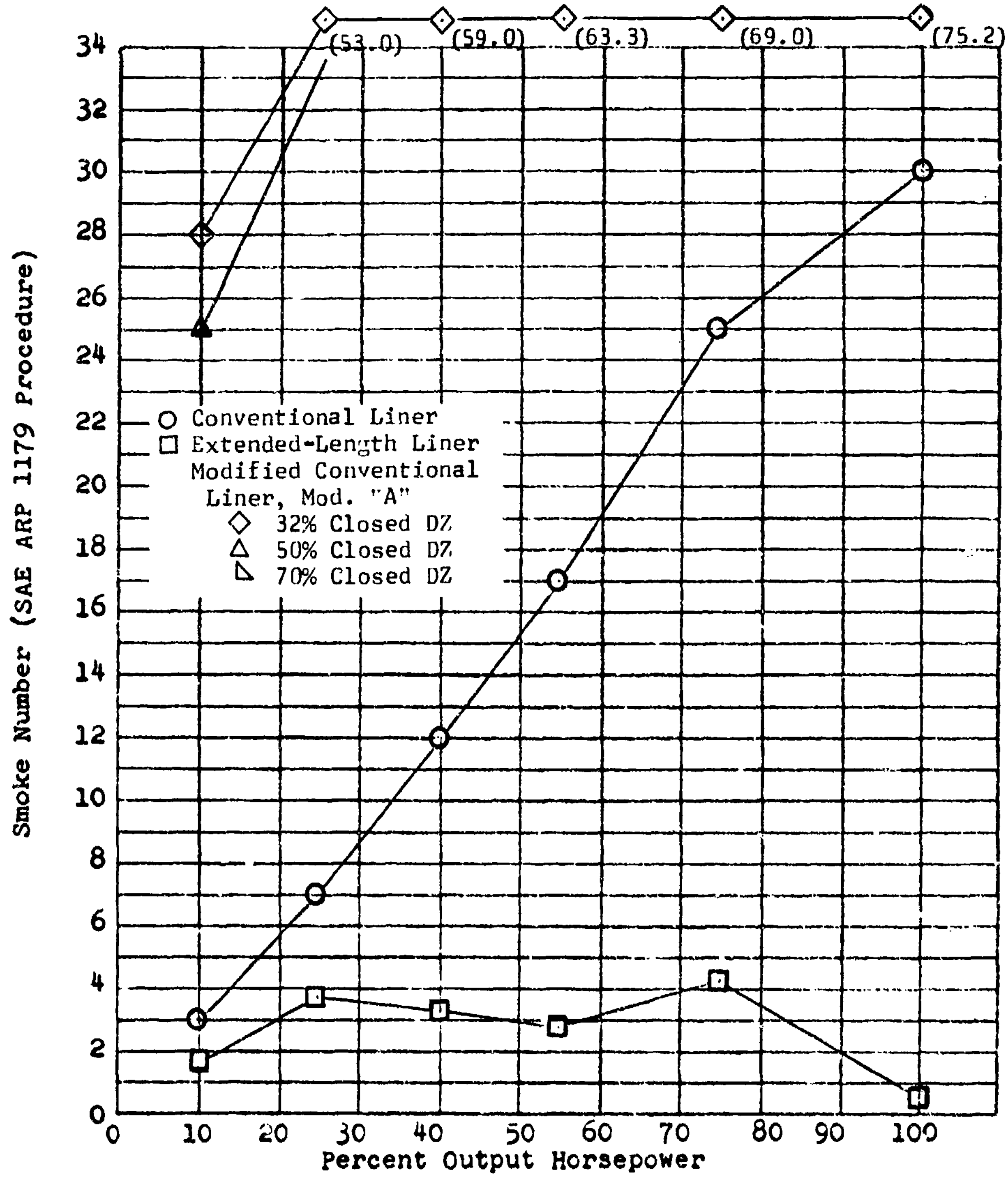

Figure 393. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Standard-Length, Modified Conventional Design Modification "A" Combustor and T63 Baseline Combustors.

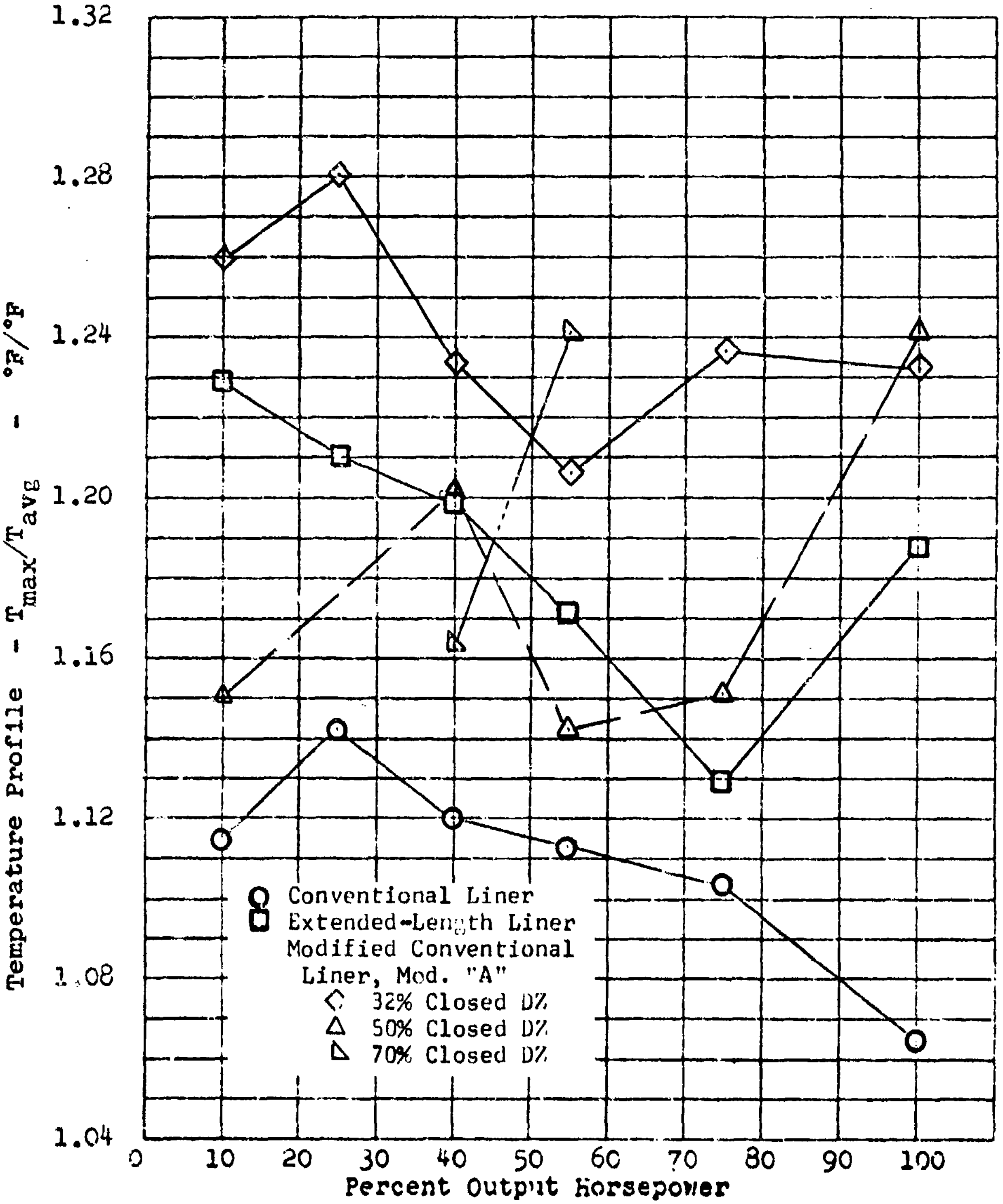

Figure 394. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Standard-Length, Modified Conventional Design, Modification "A" Combustor and T63 Baseline Combustors.

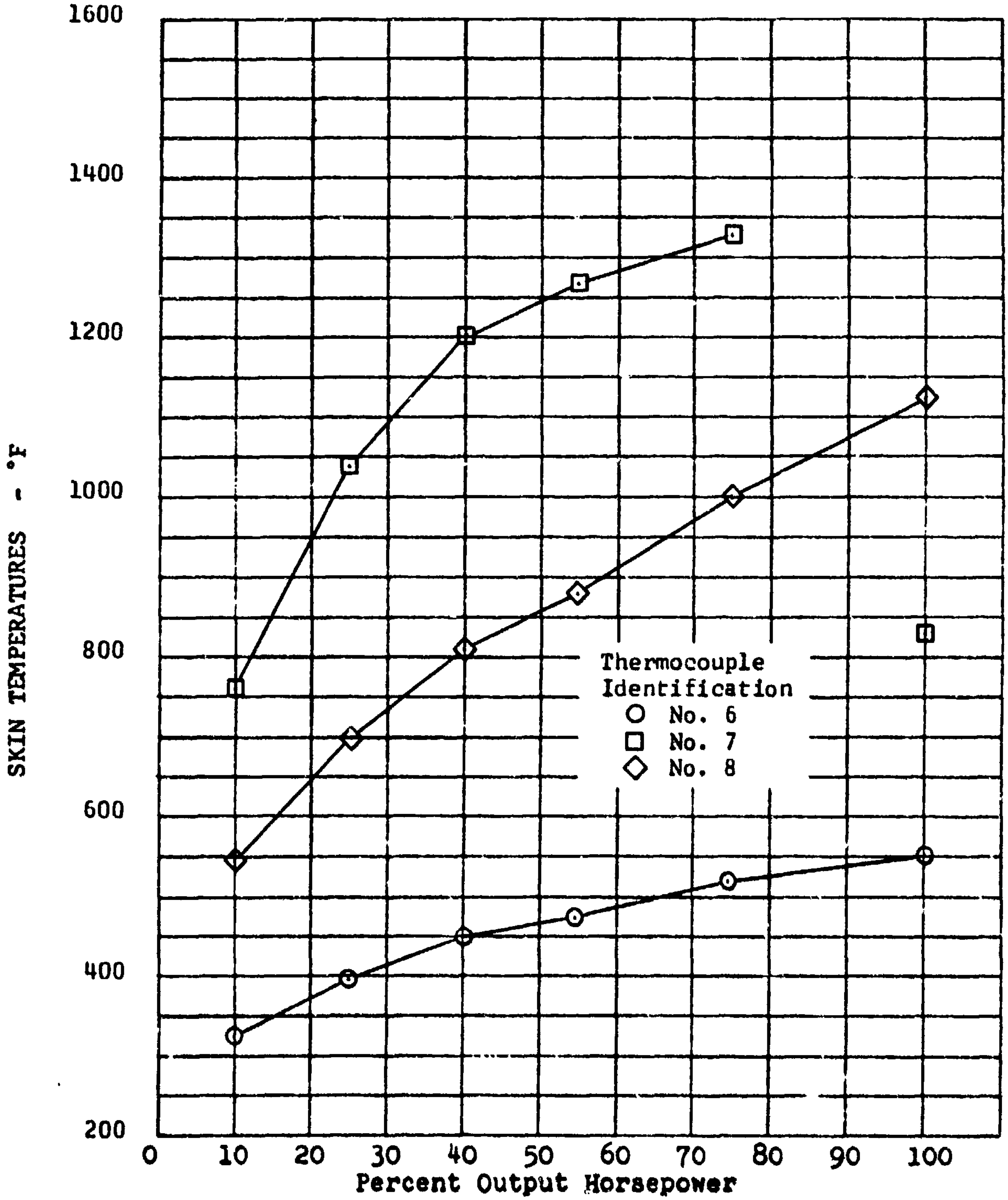

Figure 395. Nonregenerative T63-A-5A Combustor Skin Temperatures for Modified Conventional Combustor, Modification "A" Operating at 32% Closed Dilution Geometry Setting.

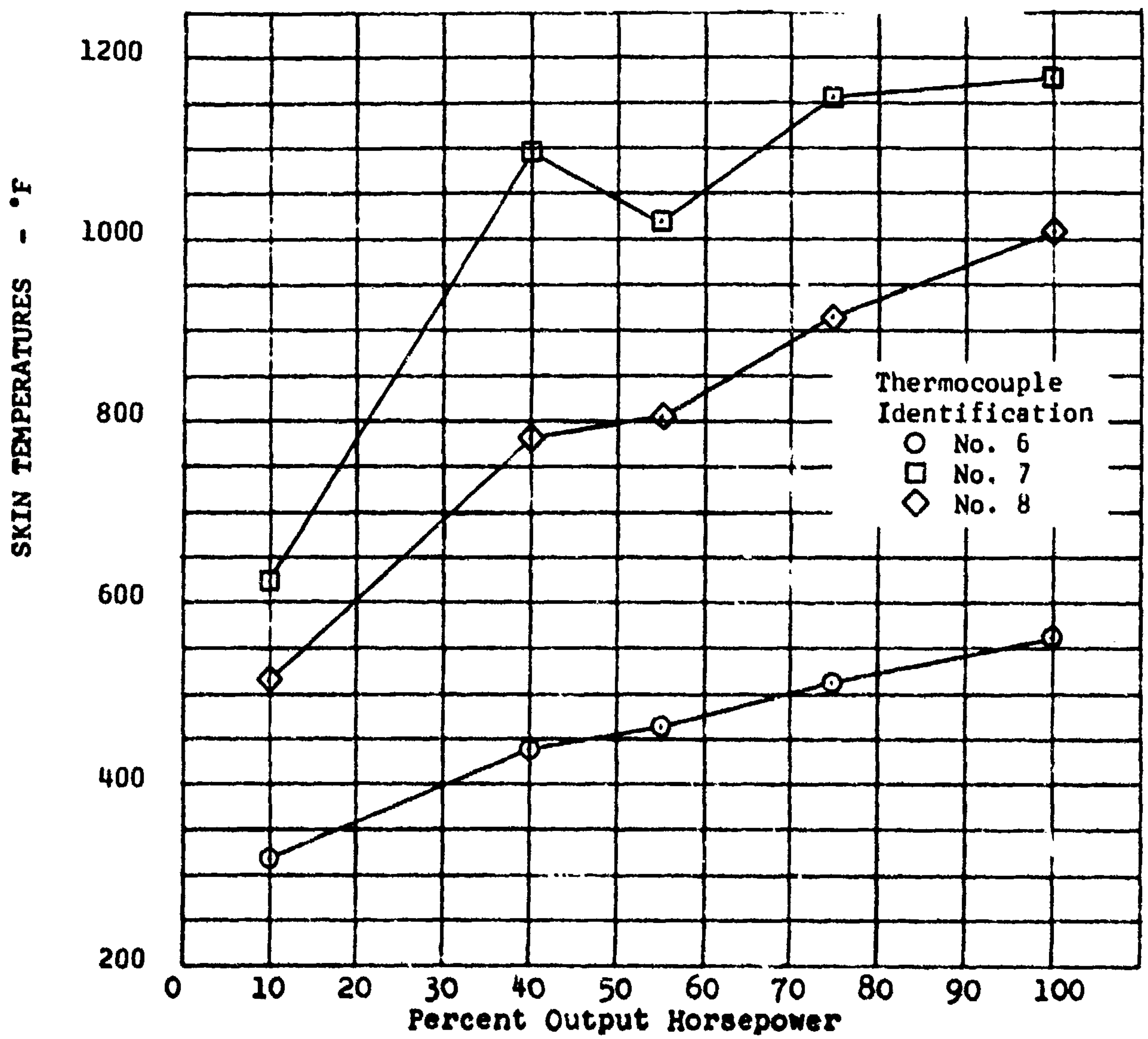

Figure 396. Nonregenerative T63-A-5A
Combustor Skin Temperatures for Modified
Conventional Combustor, Modification "A" Operating
at 50% Closed Dilution Geometry Setting.

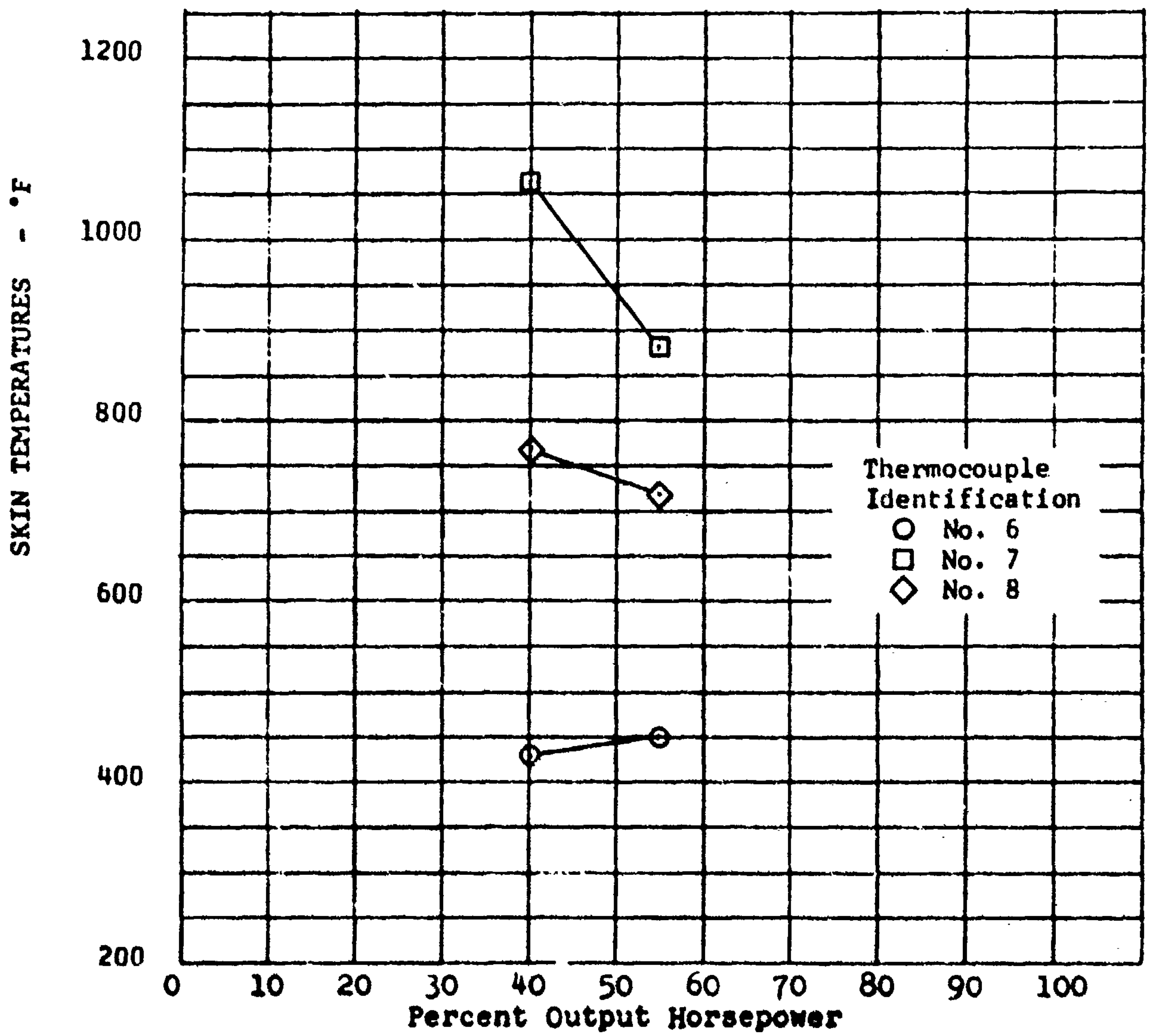

Figure 397. Nonregenerative T63-A-5A Combustor Skin Temperatures for Modified Conventional Combustor, Modification "A" Operating at 70% Closed Dilution Geometry Setting.

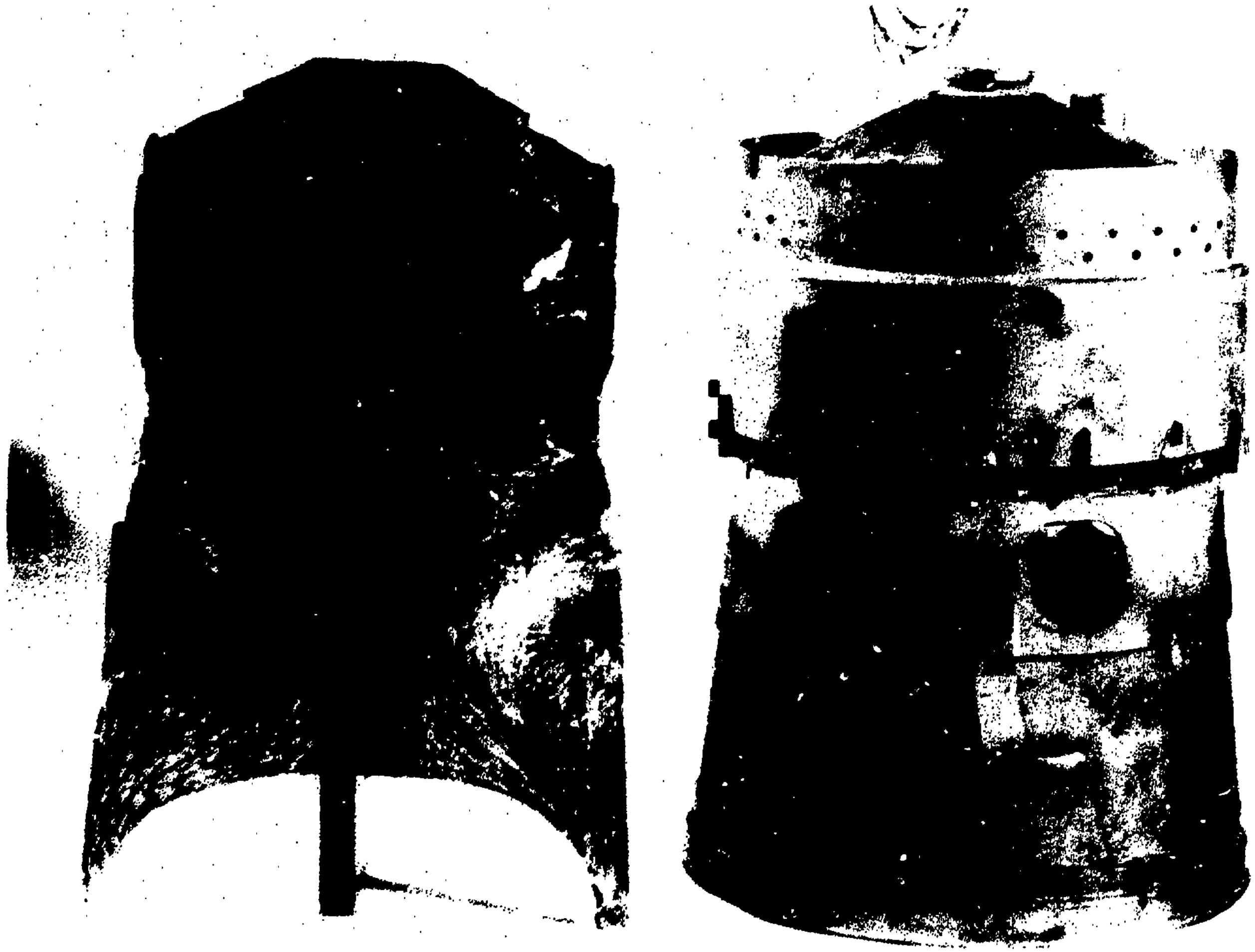

Figure 398. Final Modified Conventional Liner, Modification "A", Cold-Flow Tracing at 32% Closed Dilution Setting.

- The primary holes and dilution holes were reduced in area to increase the combustor pressure loss at the design setting from 3% to 5%.

- The dilution hole pattern was changed from six holes equally spaced to four holes spaced in a six-hole pattern.

- In order to reduce the smoke and particulates, an Ex-Cell-O air-blast pressure atomizing fuel injector was installed.

Modification "B" of the "Final Modified Conventional Combustor Liner" was tested at three different geometry settings over the nonregenerative operating conditions: 0%, 28%, and 50% closed. The 28% closed setting was the nominal design point for the nonregenerative tests. The regenerative position was intended to be 0% closed or full open.

The detailed test data results for the T63 nonregenerative evaluation are presented in Figures 399 through 411. Two of the skin thermocouple leads were broken prior to the rig tests of Modification "B"; thus no skin temperature data were recorded for this configuration. Pressure loss results from the nonregenerative tests are summarized in Table LXXXV. On the average, the pressure losses for 0%, 28%, and 50% closed dilution settings were 4%, 5%, and 7%. The mechanical operation of the combustor variable dilution geometry gave no problems during the test. With the dilution geometry set at the 28% closed position, combustion lean blowout from idle T63 nonregenerative combustor conditions was obtained at a fuel/air ratio of 0.0042 fuel/air ratio.

The measured exhaust emissions are summarized in Table LXXXVI. Comparisons of these emissions with the Conventional T63 combustor liner appear in Figures 412 through 416. The emission concentrations at the same dilution geometry settings of the Modification "B" combustor liner are connected with dashed lines. The settings which, when combined, resulted in the lowest LOH duty cycle total emissions are connected by solid lines. The hydrocarbon emissions are shown in Figure 412. A significant reduction in hydrocarbon emissions was obtained in closing the dilution holes from 0% to 28% closed. Further restriction of the dilution resulted in only a minor additional reduction. Overall, hydrocarbon mass emissions were reduced 76% below the Conventional combustor level.

The carbon monoxide concentrations in Figure 413 show that the minimum levels for the Modification "B" combustor were obtained with the 28% closed dilution geometry setting up through the 55% power conditions. At 75% and 100% power, the 50% closed setting gave lowest CO. Over the duty cycle, the Modification "B" combustor reduced carbon monoxide 56%. As can be seen in Figure 414,

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 85, READING #    945
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  8-18-72                        READING WAS TAKEN AT 1320152 HOURS

CYCLE POINT  1     VARIABLE GEOMETRY  28 % CLOSED        10 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.871 LB/SEC    AVG BURNER INLET TEMP   299. DEG F
AVG BURNER INLET PRES  43.8    PSIA      AVG BURNER OUTLET TEMP 1088. DEG F
AVG BURNER DELTA P      4.65    "HG      PRESSURE LOSS             5.21 %
OVERALL F/A RATIO     .01093  (F/P)      FUEL FLOW RATE           71.66 LB/HR
AIR LOAD FACTOR        1.1450            PATTERN FACTOR          .27307
BOT HOT SPOT: # 34 = 1292.  DEG F        MAX BOT / AVG BOT       1.1920
FUEL INLET TEMPERATURE  91.  DEG F       FUEL INLET PRESSURE       72.6   PSIA
HEAT LOADING PARAMETER  .35444E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1246.  6 1068. 15 1022. 19  915. 24  960. 27 1035. 36 1199.
ANNULUS 2  4 1243.  7 1056. 16  936. 21  879. 25  984. 34 1292. 37 1150.
ANNULUS 3  5 1416. 14  942. 17  777. 22  866. 26  955. 35 1136. 39 1028.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE            43.81    PSIA    TOTAL PRESSURE        43.84   PSIA
STATIC PRESSURE           43.5     PSIA    STATIC PRESSURE       43.60   PSIA
VELOCITY DELTA P            .53     "HG    VELOCITY DELTA P        .49    "HG
AIR TEMPERATURE            299.   DEG F    AIR TEMPERATURE        298.  DEG F
AIR VELOCITY             124.90 FT/SEC     AIR VELOCITY         119.84 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.007    "HG

AIR FLOW DATA: P-UPS= 125.2 PSIA    DELTA P= 1.56 "HG    T-REF= 108. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        263.      HZ     VOLUMETRIC FLOW RATE  11.55 GAL/HR
FUEL PRESSURE AT F/M  250.2     PSIA       FUEL TEMP AT F/M        ?9.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   41.34 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             42.58 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.61  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    1.985 %     O2  18.250 %       CO    486.6 PPM      CHX     20.0 PPM
 NO      7.2 PPM   NO2    11.0 PPM   NOX     18.2 PPM (NO(NDIR) + NO2(NDUV))
 NO     10.0 PPM   NO2    11.6 PPM   NOX     21.6 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  35.83                     CHX=   2.02
                  CHEMILUMINESCENCE NOX=   3.17,   NDIR + NDUV NOX=   2.65

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .008783
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.7470 %
   CHECK ON F/A RATIO- F/A = .008723 W/O O2, CALCULATED O2 = 18.201 %

SMOKE INDEX: 13.01
SALTZMAN NOX = 20.8                PPM
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Figure 399. Final Modified Conventional Liner, Modification "B" at Nonregenerative 10% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG F/U 70, TEST SERIES 85, READING #    946
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE: [illegible]-72                  READING WAS TAKEN AT 1343156 HOURS

CYCLE POINT  1     VARIABLE GEOMETRY    0 % CLOSED      10 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.443 LB/SEC     AVG BURNER INLET TEMP    299. DEG F
AVG BURNER INLET PRES   43.7    PSIA      AVG BURNER OUTLET TEMP 1041. DEG F
AVG BURNER DELTA P        3.58   "HG      PRESSURE LOSS              4.03 %
OVERALL F/A RATIO       .01378  (F/A)     FUEL FLOW RATE            71.56 LB/HR
AIR LOAD FACTOR          1.1621           PATTERN FACTOR            .31456
HOT HOT SPOT: # 36 = 1274.  DEG F         MAX BOT / AVG BOT        1.2240
FUEL INLET TEMPERATURE  93.   DEG F       FUEL INLET PRESSURE       72.9   PSIA
HEAT LOADING PARAMETER  .35496E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1124.  6 1120. 15  927. 19  892. 24 1033. 27 1051. 36 1274.
ANNULUS 2   4 1052.  7 1088. 16  923. 21  925. 25 1077. 34 1131. 37 1261.
ANNULUS 3   5 [illegible]  14  853. 17  797. 22  917. 26 1056. 35 1115. 39 1099.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          43.70   PSIA     TOTAL PRESSURE          43.70   PSIA
STATIC PRESSURE         43.45   PSIA     STATIC PRESSURE         43.45   PSIA
VELOCITY DELTA P          .52    "HG     VELOCITY DELTA P          .52    "HG
AIR TEMPERATURE         299.   DEG F     AIR TEMPERATURE         299.   DEG F
AIR VELOCITY           123.56 FT/SEC     AIR VELOCITY           123.31 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]           -.005   "HG

AIR FLOW DATA: P-REF= 105.2 PSIA   DELTA P= 1.60 "HG   T-REF= 107. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       255.      HZ    VOLUMETRIC FLOW RATE  11.55 GAL/HR
FUEL PRESSURE AT F/M   259.3    PSIA     FUEL TEMP AT F/M         91.  DEG F

                   ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    41.94 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE               42.72 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  3.58  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.010 %     O2  18.000 %     CO    397.0 PPM     CHX     35.0 PPM
 NO     4.2 PPM  NO2     15.2 PPM  NOX    19.3 PPM [NO(NDIR) + NO2(NDUV)]
 NO     5.3 PPM  NO2      3.7 PPM  NOX     9.0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  35.98                   CHX=   4.99
                 CHEMILUMINESCENCE NOX=   1.34,    NDIR + NDUV NOX=   2.87

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .009939
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.5322 %
  CHECK ON F/A RATIO- F/A = .009860 W/O O2, CALCULATED O2 = 18.168 %

SMOKE INDEX: 22.78
SALTZMAN NOX = 20.2              PPM
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Figure 400. Final Modified Conventional Liner, Modification "B" at Nonregenerative 10% Power - 0% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 76, TEST SERIES 85, READING #    945
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  8-16-72                      READING WAS TAKEN AT 1320:52 HOURS

CYCLE POINT  1     VARIABLE GEOMETRY  28 % CLOSED       10 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.821 LB/SEC     AVG BURNER INLET TEMP    299. DEG F
AVG BURNER INLET PRES   43.8    PSIA      AVG BURNER OUTLET TEMP 1008. DEG F
AVG BURNER DELTA P       4.65   "HG       PRESSURE LOSS            5.21 %
OVERALL F/A RATIO       .01093  (F/P)     FUEL FLOW RATE          71.66 LB/HR
AIR LOAD FACTOR         1.1450            PATTERN FACTOR          .27307
BOT HOT SPOT:  # 34 = 1202.  DEG F        MAX BOT / AVG BOT       1.1920
FUEL INLET TEMPERATURE   91.  DEG F       FUEL INLET PRESSURE      72.6   PSIA
HEAT LOADING PARAMETER  .35444E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1046.  6 1068. 15 1022. 19  915. 24  960. 27 1035. 36 1199.
ANNULUS 2    4 1043.  7 1056. 16  956. 21  879. 25  984. 34 1202. 37 1150.
ANNULUS 3    5 1016. 14  982. 17  777. 22  866. 26  955. 35 1136. 39 1028.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE            43.81   PSIA     TOTAL PRESSURE         43.84   PSIA
STATIC PRESSURE           43.55   PSIA     STATIC PRESSURE        43.60   PSIA
VELOCITY DELTA P            .53   "HG      VELOCITY DELTA P         .49   "HG
AIR TEMPERATURE           299.  DEG F      AIR TEMPERATURE        299.  DEG F
AIR VELOCITY             124.90 FT/SEC     AIR VELOCITY          119.94 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]           -.067   "HG

AIR FLOW DATA: P-REF= 105.2 PSIA    DELTA P= 1.56 "HG    T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        265.     HZ      VOLUMETRIC FLOW RATE  11.55 GAL/HR
FUEL PRESSURE AT F/M     259.2    PSIA     FUEL TEMP AT F/M        89.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    41.54 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             42.56 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                4.61  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2   1.985 %      O2  18.250 %      CO   400.6 PPM      CHX    20.0 PPM
 NO      7.0 PPM  NO2     11.0 PPM  NOX     18.0 PPM [NO(NDIR) + NO2(NDUV)]
 NO     10.0 PPM  NO2     11.6 PPM  NOX     21.6 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  35.03                CHX=    2.82
                 CHEMILUMINESCENCE NOX=   3.17,    NDIR + NDUV NOX=    2.65

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .009703
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.7479 %
   CHECK ON F/A RATIO- F/A = .009725 W/O O2, CALCULATED O2 = 18.201 %

SMOKE INDEX: 13.01
SALTZMAN NOX = 20.8                PPM
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Figure 399. Final Modified Conventional Liner, Modification "B" at Nonregenerative 10% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 65, READING #    947
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  8-10-72                      READING WAS TAKEN AT 1410123 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY  50 % CLOSED        10 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.841 LB/SEC     AVG BURNER INLET TEMP    299. DEG F
AVG BURNER INLET PRES   43.7    PSIA      AVG BURNER OUTLET TEMP  1021. DEG F
AVG BURNER DELTA P       5.23    "HG      PRESSURE LOSS             7.00 %
OVERALL F/A RATIO       .01091  (F/M)     FUEL FLOW RATE           72.31 LB/HR
AIR LOAD FACTOR          1.1607           PATTERN FACTOR           .17979
BOT HOT SPOT:  # 36 = 1150.  DEG F        MAX BOT / AVG BOT        1.1271
FUEL INLET TEMPERATURE   94.   DEG F      FUEL INLET PRESSURE      72.0   PSIA
HEAT LOADING PARAMETER  .35871E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
              ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1     2 1089.  6 1116. 15  996. 19  984. 24 1044. 27 1091. 36 1150.
ANNULUS 2     4 1117.  7 1099. 16  957. 21  930. 25 1036. 34 1049. 37 1123.
ANNULUS 3     5 1032. 14  821. 17  816. 22  924. 26  995. 35 1004. 39 1056.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          43.69    PSIA     TOTAL PRESSURE          43.71   PSIA
STATIC PRESSURE         43.43    PSIA     STATIC PRESSURE         43.44   PSIA
VELOCITY DELTA P          .54     "HG     VELOCITY DELTA P          .56    "HG
AIR TEMPERATURE          299.   DEG F     AIR TEMPERATURE          299.  DEG F
AIR VELOCITY           126.21 FT/SEC      AIR VELOCITY           127.94 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.037    "HG

AIR FLOW DATA: P-REF= 105.2 PSIA   DELTA P= 1.59 "HG    T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       268.       HZ    VOLUMETRIC FLOW RATE  11.68 GAL/HR
FUEL PRESSURE AT F/M   260.2     PSIA     FUEL TEMP AT F/M         93.   DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     40.64 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              42.14 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.21  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.107 %     O2   17.900 %     CO    717.8 PPM     CHX     15.2 PPM
 NO      5.6 PPM  NO2     12.3 PPM  NOX     17.9 PPM (NO(NDIR) + NO2(NDUV))
 NO      7.7 PPM  NO2      1.0 PPM  NOX      8.7 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  64.31                 CHX=   2.14
                 CHEMILUMINESCENCE NOX=   1.27,   NDIR + NDUV NOX=   2.64

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010495
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.2375 %
  CHECK ON F/A RATIO- F/A = .010444 W/O O2, CALCULATED O2 = 18.033 %

SMOKE INDEX: 1.51
SALTZMAN NOX = 19.2                  PPM
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Figure 401. Final Modified Conventional Liner, Modification "B" at Nonregenerative 10% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 85, READING #    948
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE: 2-16-72                     READING WAS TAKEN AT 1522:15 HOURS

CYCLE POINT  6    VARIABLE GEOMETRY  28 % CLOSED      25 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         2.204 LB/SEC     AVG BURNER INLET TEMP   353. DEG F
AVG BURNER INLET PRES  54.8     PSIA     AVG BURNER OUTLET TEMP 1149. DEG F
AVG BURNER DELTA P      5.47     "HG     PRESSURE LOSS            4.90 %
OVERALL F/A RATIO      .01222  (F/M)     FUEL FLOW RATE          96.97 LB/HR
AIR LOAD FACTOR        1.1463            PATTERN FACTOR         .33409
BOT HOT SPOT:  # 34 = 1414.  DEG F       MAX BOT / AVG BOT      1.2313
FUEL INLET TEMPERATURE  97.  DEG F       FUEL INLET PRESSURE     111.0  PSIA
HEAT LOADING PARAMETER  .38348E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1214.  6 1231. 15 1117. 19  999. 24 107[illegible]. 27 1176. 36 1371.
ANNULUS 2   4 1198.  7 1221. 16 1053. 21  984. 25 1107. 34 1414. 37 1328.
ANNULUS 3   5 1179. 14  979. 17  868. 22  977. 26 1089. 35 1337. 39 1201.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           54.81    PSIA    TOTAL PRESSURE         54.83    PSIA
STATIC PRESSURE          54.52    PSIA    STATIC PRESSURE        54.47    PSIA
VELOCITY DELTA P          .60      "HG    VELOCITY DELTA P        .72      "HG
AIR TEMPERATURE          353.    DEG F    AIR TEMPERATURE        353.    DEG F
AIR VELOCITY            123.01 FT/SEC     AIR VELOCITY          134.59 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.030     "HG

AIR FLOW DATA: P-REF= 104.0 PSIA   DELTA P= 2.31 "HG    T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      359.       HZ     VOLUMETRIC FLOW RATE  15.69 GAL/HR
FUEL PRESSURE AT F/M  308.0     PSIA      FUEL TEMP AT F/M         96.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   52.13 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            53.28 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               5.46  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.107 %     O2  16.400 %      CO    216.4 PPM     CHX     5.0 PPM
 NO     14.1 PPM  NO2     8.5 PPM  NOX     22.6 PPM [NO(NDIR) + NO2(NDUV)]
 NO     17.1 PPM  NO2      .5 PPM  NOX     17.6 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  17.33               CHX=     .63
                 CHEMILUMINESCENCE NOX=   2.31,    NDIR + NDUV NOX=   2.97

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011050
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.4373 %
   CHECK ON F/A RATIO- F/A = .010192 W/O O2, CALCULATED O2 = 18.048 %

SMOKE INDEX:  13.62
SALTZMAN NOX = 28.2              PPM
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Figure 402. Final Modified Conventional Liner, Modification "B" at Nonregenerative 25% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 85, READING #    949
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE: 8-16-72                      READING WAS TAKEN AT 1542:40 HOURS

CYCLE POINT  6    VARIABLE GEOMETRY  50 % CLOSED       25 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.234 LB/SEC    AVG BURNER INLET TEMP    353. DEG F
AVG BURNER INLET PRES   55.3    PSIA     AVG BURNER OUTLET TEMP  1161. DEG F
AVG BURNER DELTA P       7.53    "HG     PRESSURE LOSS              6.69 %
OVERALL F/A RATIO       .01205  (F/P)    FUEL FLOW RATE            96.93 LB/HR
AIR LOAD FACTOR         1.1517           PATTERN FACTOR           .18901
BOT HOT SPOT:  # 36 = 1314.  DEG F       MAX BOT / AVG BOT        1.1315
FUEL INLET TEMPERATURE   98.  DEG F      FUEL INLET PRESSURE      110.1   PSIA
HEAT LOADING PARAMETER  .37987E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
              ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1     2 1257.  6 1264. 15 1112. 19 1096. 24 1177. 27 1228. 36 1314.
ANNULUS 2     4 1281.  7 1263. 16 1065. 21 1045. 25 1173. 34 1230. 37 1297.
ANNULUS 3     5 1189. 14  906. 17  905. 22 1037. 26 1135. 35 1194. 39 1217.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          55.29   PSIA     TOTAL PRESSURE          55.34   PSIA
STATIC PRESSURE         55.02   PSIA     STATIC PRESSURE         55.01   PSIA
VELOCITY DELTA P          .54    "HG     VELOCITY DELTA P          .67    "HG
AIR TEMPERATURE          354.  DEG F     AIR TEMPERATURE          353.  DEG F
AIR VELOCITY           116.13 FT/SEC     AIR VELOCITY           129.57 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          -.107    "HG

AIR FLOW DATA: P-REF= 104.1 PSIA   DELTA P= 2.37 "HG    T-REF= 103. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        359.      HZ   VOLUMETRIC FLOW RATE   15.69 GAL/HR
FUEL PRESSURE AT F/M    308.1     PSIA   FUEL TEMP AT F/M         97.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     51.61 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              53.53 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 7.48  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.352 %     O2  15.700 %      CO    365.9 PPM      CHX      4.2 PPM
 NO      9.1 PPM  NO2     10.2 PPM  NOX     19.3 PPM (NO(NDIR) + NO2(NDUV))
 NO     14.3 PPM  NO2      1.5 PPM  NOX     15.8 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  29.71                 CHX=     .54
                  CHEMILUMINESCENCE NOX=   2.11,  NDIR + NDUV NOX=    2.57

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .012602
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.2216 %
   CHECK ON F/A RATIO- F/A = .011420 W/O O2. CALCULATED O2 = 17.693 %

SMOKE INDEX: 4.26
SALTZMAN NOX = 24.6              PPM
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Figure 403. Final Modified Conventional Liner, Modification "B" at Nonregenerative 25% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 85, READING #    950
63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  6-16-72                       READING WAS TAKEN AT 1602:54 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  28 % CLOSED       40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.554 LB/SEC     AVG BURNER INLET TEMP    399. DEG F
AVG BURNER INLET PRES   54.0    PSIA      AVG BURNER OUTLET TEMP 1256. DEG F
AVG BURNER DELTA P       6.74    "HG      PRESSURE LOSS             5.18 %
OVERALL F/A RATIO      .01320   (F/M)     FUEL FLOW RATE          121.37 LB/HR
AIR LOAD FACTOR         1.1697            PATTERN FACTOR           .39323
HOT HOT SPOT:  # 34 = 1593.   DEG F       MAX BOT / AVG BOT       1.2683
FUEL INLET TEMPERATURE   99.   DEG F      FUEL INLET PRESSURE     154.7   PSIA
HEAT LOADING PARAMETER   .41114E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1329.  6 1346. 15 1218. 19 1095. 24 1164. 27 1280. 36 1507.
ANNULUS 2   4 1298.  7 1341. 16 1145. 21 1086. 25 1187. 34 1593. 37 1449.
ANNULUS 3   5 1286. 14 1380. 17  945. 22 1062. 26 1183. 35 1477. 39 1308.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          63.95    PSIA     TOTAL PRESSURE          64.03   PSIA
STATIC PRESSURE         63.60    PSIA     STATIC PRESSURE         63.68   PSIA
VELOCITY DELTA P          .72     "HG     VELOCITY DELTA P          .71    "HG
AIR TEMPERATURE          399.   DEG F     AIR TEMPERATURE          399.   DEG F
AIR VELOCITY           128.36 FT/SEC      AIR VELOCITY           127.48 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.165    "HG

AIR FLOW DATA: P-REF= 143.3 PSIA    DELTA P= 3.13 "HG    T-REF= 103. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       449.      HZ     VOLUMETRIC FLOW RATE  19.66 GAL/HR
FUEL PRESSURE AT F/M   304.0    PSIA      FUEL TEMP AT F/M          98.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    60.68 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             61.99 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                6.66  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.205 %     O2  15.500 %     CO    166.8 PPM     CHX      2.3 PPM
 NO     19.0 PPM  NO2     8.9 PPM  NOX     27.9 PPM (NO(NDIR) + NO2(NDUV))
 NO     23.6 PPM  NO2      .0 PPM  NOX     23.6 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12.38                  CHX=     .27
                  CHEMILUMINESCENCE NOX=   2.88,    NDIR + NDUV NOX=   3.40

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .011991
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6801 %
   CHECK ON F/A RATIO- F/A = .010627 W/O O2, CALCULATED O2 = 17.916 %

SMOKE INDEX: 14.29
SALTZMAN NOX = 32.4                PPM
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Figure 404. Final Modified Conventional Liner, Modification "B" at Nonregenerative 40% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 85, READING #    951
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  8-16-72                        READING WAS TAKEN AT 1624138 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  50 % CLOSED       40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.543 LB/SEC    AVG BURNER INLET TEMP    398. DEG F
AVG BURNER INLET PRES   64.5   PSIA      AVG BURNER OUTLET TEMP 1269. DEG F
AVG BURNER DELTA P       9.29   "HG      PRESSURE LOSS             7.03 %
OVERALL F/A RATIO       .01325  (F/M)    FUEL FLOW RATE          121.29 LB/HR
AIR LOAD FACTOR         1.1552           PATTERN FACTOR          .16820
BOT HOT SPOT:  # 36 = 1416.  DEG F       MAX BOT / AVG BOT       1.1155
FUEL INLET TEMPERATURE 100.  DEG F       FUEL INLET PRESSURE      153.9  PSIA
HEAT LOADING PARAMETER  .40785E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1372.  6 1415. 15 1210. 19 1196. 24 1291. 27 1344. 36 1416.
ANNULUS 2   4 1389.  7 1402. 16 1156. 21 1145. 25 1284. 34 1359. 37 1393.
ANNULUS 3   5 1307. 14  985. 17  964. 22 1130. 26 1243. 35 1337. 39 1316.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE             64.44   PSIA    TOTAL PRESSURE          64.50   PSIA
STATIC PRESSURE            64.06   PSIA    STATIC PRESSURE         64.15   PSIA
VELOCITY DELTA P             .76    "HG    VELOCITY DELTA P          .70    "HG
AIR TEMPERATURE             398.  DEG F    AIR TEMPERATURE          398.  DEG F
AIR VELOCITY              130.75 FT/SEC    AIR VELOCITY           125.75 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            -.126    "HG

AIR FLOW DATA: P-REF= 143.6 PSIA   DELTA P= 3.09 "HG   T-REF= 102. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       449.      HZ      VOLUMETRIC FLOW RATE  19.66 GAL/HR
FUEL PRESSURE AT F/M   343.0    PSIA      FUEL TEMP AT F/M          99.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   59.91 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            62.22 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               9.22  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.500 %     O2  18.000 %     CO   262.7 PPM      CHX      2.8 PPM
 NO     19.0 PPM   NO2    11.0 PPM  NOX    30.0 PPM (NO(NDIR) + NO2(NDUV))
 NO     21.6 PPM   NO2      .8 PPM  NOX    22.3 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  19.43                 CHX=     .33
                   CHEMILUMINESCENCE NOX=  2.71,   NDIR + NDUV NOX=   3.68

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .011790
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.4669 %
   CHECK ON F/A RATIO- F/A = .012070 W/O O2, CALCULATED O2 = 17.495 %

SMOKE INDEX: 4.28
SALTZMAN NOX = 31.2                PPM
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Figure 405. Final Modified Conventional Liner, Modification "B" at Nonregenerative 40% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 85, READING #     952
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  8-16-72                      READING WAS TAKEN AT 1645: 2 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY   0 % CLOSED       40 % POWER SETTING

                     ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         2.559 LB/SEC    AVG BURNER INLET TEMP   397. DEG F
AVG BURNER INLET PRES  64.6    PSIA     AVG BURNER OUTLET TEMP 1304. DEG F
AVG BURNER DELTA P      5.19    "HG     PRESSURE LOSS            3.95 %
OVERALL F/A RATIO      .01313  (F/P)    FUEL FLOW RATE         120.96 LB/HR
AIR LOAD FACTOR        1.1586           PATTERN FACTOR          .22123
BOT HOT SPOT:  # 37 = 1504.  DEG F      MAX BOT / AVG BOT      1.1539
FUEL INLET TEMPERATURE 100.  DEG F      FUEL INLET PRESSURE    155.8  PSIA
HEAT LOADING PARAMETER  .40564E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1440.  6 1438. 15 1162. 19 1125. 24 1293. 27 1312. 36 1479.
ANNULUS 2   4 1358.  7 1389. 16 1170. 21 1168. 25 1352. 34 1421. 37 1504.
ANNULUS 3   5 1398. 14 1085. 17 1015. 22 1147. 26 1330. 35 1459. 39 1339.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE           64.65   PSIA   TOTAL PRESSURE           64.64  PSIA
STATIC PRESSURE          64.29   PSIA   STATIC PRESSURE          64.32  PSIA
VELOCITY DELTA P           .73    "HG   VELOCITY DELTA P           .64   "HG
AIR TEMPERATURE           397.  DEG F   AIR TEMPERATURE           397.  DEG F
AIR VELOCITY            127.90 FT/SEC   AIR VELOCITY            120.23 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]         .013    "HG

AIR FLOW DATA: P-REF= 103.4 PSIA   DELTA P= 3.13 "HG   T-REF= 102. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      446.      HZ    VOLUMETRIC FLOW RATE  19.61 GAL/HR
FUEL PRESSURE AT F/M  302.8     PSIA    FUEL TEMP AT F/M       100.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    62.09 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             63.16 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.20  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.411 %     O2  12.800 %     CO   103.4 PPM     CHX     2.2 PPM
 NO     26.0 PPM  NO2     10.6 PPM  NOX    36.6 PPM (NO(NDIR) + NO2(NDUV))
 NO     27.5 PPM  NO2      1.9 PPM  NOX    29.5 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  13.60                  CHX=    .20
                  CHEMILUMINESCENCE NOX=   3.61,   NDIR + NDUV NOX=   4.49

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010022
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.0013 %
   CHECK ON F/A RATIO- F/A = .011611 W/O O2. CALCULATED O2 = 17.626 %

SMOKE INDEX: 36.37
SALTZMAN NOX = 43.0              PPM
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Figure 406. Final Modified Conventional Liner, Modification "B" at Nonregenerative 40% Power - 0% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 85, READING #     953
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  9-18-72                      READING WAS TAKEN AT 1733: 0 HOURS

CYCLE POINT  4    VARIABLE GEOMETRY  28 % CLOSED        55 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.759 LB/SEC    AVG BURNER INLET TEMP   430. DEG F
AVG BURNER INLET PRES  71.5    PSIA      AVG BURNER OUTLET TEMP 1378. DEG F
AVG BURNER DELTA P      7.22    "HG      PRESSURE LOSS             4.97 %
OVERALL F/A RATIO      .01447  (F/F)     FUEL FLOW RATE          143.72 LB/HR
AIR LOAD FACTOR        1.1514            PATTERN FACTOR           .42959
BOT HOT SPOT: # 34 = 1785.  DEG F        MAX BOT / AVG BOT        1.2955
FUEL INLET TEMPERATURE 102.  DEG F       FUEL INLET PRESSURE     202.3  PSIA
HEAT LOADING PARAMETER  .43601E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1456.  6 1461. 15 1316. 19 1190. 24 1284. 27 1392. 36 1687.
ANNULUS 2   4 1429.  7 1488. 16 1236. 21 1181. 25 1314. 34 1785. 37 1607.
ANNULUS 3   5 14??. 14 1167. 17 1206. 22 1147. 26 1303. 35 1656. 39 1426.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE         71.40    PSIA     TOTAL PRESSURE          71.51   PSIA
STATIC PRESSURE        71.08    PSIA     STATIC PRESSURE         71.22   PSIA
VELOCITY DELTA P         .66    "HG      VELOCITY DELTA P          .59   "HG
AIR TEMPERATURE         430.   DEG F     AIR TEMPERATURE          430.  DEG F
AIR VELOCITY          118.28 FT/SEC      AIR VELOCITY           111.20 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.217    "HG

AIR FLOW DATA: P-REF= 103.0 PSIA   DELTA P= 3.64 "HG    T-REF=  80. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       533.       HZ     VOLUMETRIC FLOW RATE  23.33 GAL/HR
FUEL PRESSURE AT F/M   344.5     PSIA     FUEL TEMP AT F/M        102.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE       67.01 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                69.42 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   7.12  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.303 %     O2  13.000 %     CO    134.7 PPM      CHX       2.2 PPM
 NO     29.5 PPM  NO2      8.9 PPM  NOX     38.4 PPM (NO(NDIR) + NO2(NDUV))
 NO     27.5 PPM  NO2      1.9 PPM  NOX     29.5 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  10.40                    CHX=    .23
                  CHEMILUMINESCENCE NOX=   3.28,    NDIR + NDUV NOX=    4.28

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .014304
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.0308 %
   CHECK ON F/A RATIO- F/A = .011885 W/O O2, CALCULATED O2 = 17.700 %

SMOKE INDEX: 24.24
SALTZMAN NOX = 40.2                PPM
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Figure 407. Final Modified Conventional Liner, Modification "B" at Nonregenerative 55% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 85, READING #     954
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE: 8-16-72                       READING WAS TAKEN AT 1754140 HOURS

CYCLE POINT  4     VARIABLE GEOMETRY  50 % CLOSED        55 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW            2.750 LB/SEC     AVG BURNER INLET TEMP    430. DEG F
AVG BURNER INLET PRES     71.0    PSIA      AVG BURNER OUTLET TEMP 1397. DEG F
AVG BURNER DELTA P        10.04    "HG      PRESSURE LOSS              6.87 %
OVERALL F/A RATIO        .01464  (F/M)      FUEL FLOW RATE           144.89 LB/HR
AIR LOAD FACTOR          1.1431             PATTERN FACTOR           .18434
BOT HOT SPOT:  # 36 = 1576.  DEG F          MAX BOT / AVG BOT        1.1276
FUEL INLET TEMPERATURE 141.  DEG F          FUEL INLET PRESSURE      202.9  PSIA
HEAT LOADING PARAMETER  .43768E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1502.  6 1530. 15 1313. 19 1313. 24 1424. 27 1488. 36 1576.
ANNULUS 2   4 1523.  7 1524. 16 1261. 21 1257. 25 1428. 34 1541. 37 1558.
ANNULUS 3   5 1425. 14 1466. 17 1031. 22 1242. 26 1378. 35 1506. 39 1466.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          71.73    PSIA     TOTAL PRESSURE          71.79   PSIA
STATIC PRESSURE         71.32    PSIA     STATIC PRESSURE         71.43   PSIA
VELOCITY DELTA P          .84     "HG     VELOCITY DELTA P          .72    "HG
AIR TEMPERATURE          431.   DEG F     AIR TEMPERATURE          430.   DEG F
AIR VELOCITY          132.76 FT/SEC       AIR VELOCITY          123.37 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))      -.110    "HG

AIR FLOW DATA: P-REF= 183.1 PSIA   DELTA P= 3.59 "HG    T-REF=  95. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       537.       HZ     VOLUMETRIC FLOW RATE  23.50 GAL/HR
FUEL PRESSURE AT F/M   347.1      PSIA     FUEL TEMP AT F/M        101.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    68.83 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                69.25 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   9.99  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.001 %     O2  12.500 %      CO    101.3 PPM     CHX      1.7 PPM
 NO     25.3 PPM  NO2      9.7 PPM  NOX     35.1 PPM (NO(NDIR) + NO2(NDUV))
 NO     29.5 PPM  NO2       .0 PPM  NOX     29.5 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12.18                  CHX=     .10
                 CHEMILUMINESCENCE NOX=   3.24,    NDIR + NDUV NOX=    3.86

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .017134
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8849 %
   CHECK ON F/A RATIO= F/A = .013448 W/O O2, CALCULATED O2 = 17.004 %

SMOKE INDEX: 10.20
SALTZMAN NOX = 42.1            PPM
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Figure 408. Final Modified Conventional Liner, Modification "B" at Nonregenerative 55% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 85, READING #    955
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE: 8-15-72                        READING WAS TAKEN AT 1838: 3 HOURS

CYCLE POINT  3     VARIABLE GEOMETRY  50 % CLOSED        75 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.997 LB/SEC      AVG BURNER INLET TEMP    473. DEG F
AVG BURNER INLET PRES   84.9    PSIA       AVG BURNER OUTLET TEMP 1549. DEG F
AVG BURNER DELTA P      10.82    "HG       PRESSURE LOSS              6.56 %
OVERALL F/A RATIO       .01547  (F/P)      FUEL FLOW RATE           177.74 LB/HR
AIR LOAD FACTOR         1.1307             PATTERN FACTOR           .19966
BOT HOT SPOT: # 36 = 1764.  DEG F          MAX BOT / AVG BOT        1.1389
FUEL INLET TEMPERATURE 184.  DEG F         FUEL INLET PRESSURE      284.9  PSIA
HEAT LOADING PARAMETER  .47601E+0. BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1553.  6 1649. 15 1464. 19 1463. 24 1566. 27 1633. 36 1764.
ANNULUS 2    4 1684.  7 1696. 16 1397. 21 1408. 25 1563. 34 1718. 37 1738.
ANNULUS 3    5 1581. 14 1193. 17 1125. 22 1372. 26 1517. 35 1685. 39 1620.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE            80.94    PSIA    TOTAL PRESSURE          80.95    PSIA
STATIC PRESSURE           80.59    PSIA    STATIC PRESSURE         80.61    PSIA
VELOCITY DELTA P            .71     "HG    VELOCITY DELTA P          .70     "HG
AIR TEMPERATURE            473.   DEG F    AIR TEMPERATURE          473.   DEG F
AIR VELOCITY             117.56 FT/SEC     AIR VELOCITY           116.46 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            -.027     "HG

AIR FLOW DATA: P-REF= 102.7 PSIA    DELTA P= 4.27 "HG    T-REF=  93. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        842.     HZ      VOLUMETRIC FLOW RATE   28.09 GAL/HR
FUEL PRESSURE AT F/M    359.7    PSIA      FUEL TEMP AT F/M         184.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    75.83 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE            78.45 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               10.00  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    3.186 %      O2  12.204 %      CO    131.3 PPM      CHX        .2 PPM
 NO     35.2 PPM   NO2      8.9 PPM   NOX    44.0 PPM (NO(NDIR) + NO2(NDUV))
 NO     39.2 PPM   NO2       .0 P     NOX    39.2 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   7.84                     CHX=     .02
                  CHEMILUMINESCENCE NOX=   3.84,    NDIR + NDUV NOX=    4.32

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .018788
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7889 %
   CHECK ON F/A RATIO- F/A = .014854 W/O O2, CALCULATED O2 = 16.083 %

SMOKE INDEX: 19.76
SALTZMAN NOX = 52.5              PPM
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Figure 409. **Final Modified Conventional Liner, Modification "B" at Nonregenerative 75% Power - 50% Closed DZ.**

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T63 COMBUSTOR EXPERIMENTS - RIG 6/U 70, TEST SERIES 85, READING #    956
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE:  8-18-72                       READING WAS TAKEN AT 1859:44 HOURS

CYCLE POINT  3     VARIABLE GEOMETRY  28 X CLOSED        75 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          3.001 LB/SEC      AVG BURNER INLET TEMP    472. DEG F
AVG BURNER INLET PRES   81.2    PSIA       AVG BURNER OUTLET TEMP 1541. DEG F
AVG BURNER DELTA P       7.48    "HG       PRESSURE LOSS              4.53 X
OVERALL F/A RATIO       .01647  (F/F)      FUEL FLOW RATE           177.91 LB/HR
AIR LOAD FACTOR         1.1278             PATTERN FACTOR           .45878
BOT HOT SPOT: # 34 = 2032.   DEG F         MAX BOT / AVG BOT        1.3183
FUEL INLET TEMPERATURE 105.  DEG F         FUEL INLET PRESSURE      286.8  PSIA
HEAT LOADING PARAMETER   .47488E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1655.  6 1660. 15 1447. 19 1297. 24 1413. 27 1546. 36 1893.
ANNULUS 2   4 1802.  7 1666. 16 1357. 21 1294. 25 1451. 34 2032. 37 1832.
ANNULUS 3   5 1622. 14 1291. 17 1184. 22 1270. 26 1441. 35 1862. 39 1627.

LEFT SIDE               *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE            81.22    PSIA    TOTAL PRESSURE           81.23   PSIA
STATIC PRESSURE           82.83    PSIA    STATIC PRESSURE          80.98   PSIA
VELOCITY DELTA P            .81     "HG    VELOCITY DELTA P           .68    "HG
AIR TEMPERATURE           472.    DEG F    AIR TEMPERATURE          472.   DEG F
AIR VELOCITY             125.45 FT/SEC     AIR VELOCITY            115.20 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))             -.019    "HG

AIR FLOW DATA: P-MEFF= 123.8 PSIA    DELTA P= 4.26 "HG    T-REF=  91. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY         583.       HZ     VOLUMETRIC FLOW RATE  28.04 GAL/HR
FUEL PRESSURE AT F/M     382.4      PSIA     FUEL TEMP AT F/M        185.  DEG F

                    ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     77.55 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              79.83 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 7.47  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.658 X      O2  12.688 X       CO    154.7 PPM      CHX       .8 PPM
 NO     10.0 PPM   NO2     11.5 PPM   NOX     42.4 PPM (NO(NDIR) + NO2(NDUV))
 NO     34.3 PPM   NO2      1.9 PPM   NOX     36.3 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    9.24                   CHX=     .08
                  CHEMILUMINESCENCE NOX=  3.98,    NDIR + NDUV NOX=     4.18

   CALCULATED FUEL/AIR RATIO F OF CHEMICAL ANALYSIS:          .01...
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6904 X
   CHECK ON F/A RATIO- F/A = .012722 W/O O2, CALCULATED O2 = 17.286 X

SMOKE INDEX: 36.15
SALTZMAN NOX = 53.8                PPM
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Figure 410. Final Modified Conventional Liner, Modification "B" at Nonregenerative 75% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 85, READING #    957
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN AT STD T63 INLET CONDITIONS
TEST DATE: 8-16-72                      READING WAS TAKEN AT 1927: 7 HOURS

CYCLE POINT  2    VARIABLE GEOMETRY  50 % CLOSED      100 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          3.245 LB/SEC    AVG BURNER INLET TEMP    523. DEG F
AVG BURNER INLET PRES   92.4    PSIA     AVG BURNER OUTLET TEMP 1782. DEG F
AVG BURNER DELTA P       11.30   "HG     PRESSURE LOSS             6.01 %
OVERALL F/A RATIO       .01961  (F/P)    FUEL FLOW RATE          229.09 LB/HR
AIR LOAD FACTOR          1.1005          PATTERN FACTOR           .20536
BOT HOT SPOT: # 36 = 2041.  DEG F        MAX BOT / AVG BOT        1.1451
FUEL INLET TEMPERATURE 148.  DEG F       FUEL INLET PRESSURE      439.2  PSIA
HEAT LOADING PARAMETER  .53732E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
          ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1902.  6 1923. 15 1705. 19 1600. 24 1749. 27 1836. 36 2041.
ANNULUS 2  4 1934.  7 1949. 16 1617. 21 1621. 25 1750. 34 2035. 37 2035.
ANNULUS 3  5 1813. 14 1401. 17 1278. 22 1556. 26 1720. 35 1985. 39 1897.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          92.39   PSIA    TOTAL PRESSURE           92.46   PSIA
STATIC PRESSURE         91.97   PSIA    STATIC PRESSURE          92.01   PSIA
VELOCITY DELTA P          .85    "HG    VELOCITY DELTA P           .92    "HG
AIR TEMPERATURE          523.  DEG F    AIR TEMPERATURE           523.  DEG F
AIR VELOCITY           123.41 FT/SEC    AIR VELOCITY            128.45 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.147    "HG

AIR FLOW DATA: P-REF= 102.2 PSIA   DELTA P= 5.01 "HG   T-REF=  89. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       859.      HZ    VOLUMETRIC FLOW RATE  37.31 GAL/HR
FUEL PRESSURE AT F/M   562.9    PSIA    FUEL TEMP AT F/M        107.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   86.87 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            89.58 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE              11.23  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2    3.574 %     O2  11.600 %     CO     97.4 PPM    CHX      .2 PPM
 NO    57.9 PPM  NO2      7.2 PPM  NOX     65.1 PPM (NO(NDIR) + NO2(NDUV))
 NO    61.7 PPM  NO2      2.0 PPM  NOX     63.7 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=     4.90              CHX=     .01
                 CHEMILUMINESCENCE NOX=    5.26,   NDIR + NDUV NOX=   5.38

  CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .021460
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8461 %
   CHECK ON F/A RATIO- F/A = .017028 W/O O2. CALCULATED O2 = 16.014 %

SMOKE INDEX: 31.03
SALTZMAN NOX = 75.9              PPM
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Figure 411. Final Modified Conventional Liner, Modification "B" at Nonregenerative 100% Power - 50% Closed DZ.

TABLE LXXXV. COMPARISON OF COMBUSTOR PRESSURE LOSS (%) FOR FINAL DESIGN MODIFIED CONVENTIONAL MODIFICATION "B" COMBUSTOR LINER AND BASELINE COMBUSTORS AT NONREGENERATIVE OPERATING CONDITIONS.

	Cycle Point					
	1	6	5	4	3	2
I. Conventional T63-A-5A Liner	4.63	4.51	4.53	4.44	4.38	4.14
II. Extended-Length Liner	5.10	4.61	5.09	4.91	4.74	4.59
III. Final Design Modified Conventional Liner Mod. "B"						
0% Closed	4.03		3.95			
28% Closed	5.21	4.90	5.18	4.97	4.53	
50% Closed	7.00	6.69	7.08	6.87	6.56	6.01

TABLE LXXXVI. EMISSION DATA OF FINAL DESIGN, MODIFIED CONVENTIONAL COMBUSTOR LINER MODIFICATION "B" OPERATING AT T63 NONREGENERATIVE COMBUSTOR CONDITIONS

Dilution Zone Variable Geometry Setting	Cycle Point					
	1	6	5	4	3	2
0% Closed						
CO, (ppm)	397.0		183.4			
C_xH_y, (ppm)	35.0		2.2			
NO_x, (NDIR & NDUV) (ppm)	19.3		36.6			
NO_x, (CL) (ppm)	9.0		29.5			
NO_x, (Saltzman) (ppm)	20.2		43.0			
Smoke Index	22.8		36.4			
28% Closed						
CO, (ppm)	400.6	216.4	166.8	154.7	154.7	
C_xH_y, (ppm)	20.0	5.0	2.3	2.2	.8	
NO_x, (NDIR & NDUV) (ppm)	18.0	22.6	27.9	38.4	42.4	
NO_x, (CL) (ppm)	21.6	17.6	23.6	29.5	36.3	
NO_x, (Saltzman) (ppm)	20.8	28.2	32.4	40.2	53.8	
Smoke Index	13.0	13.6	14.3	24.2	38.1	
50% Closed						
CO, (ppm)	717.8	365.9	262.7	181.3	131.3	97.4
C_xH_y, (ppm)	15.2	4.2	2.8	1.7	.2	.2
NO_x, (NDIR & NDUV) (ppm)	17.9	19.3	30.0	35.1	44.0	65.1
NO_x, (CL) (ppm)	8.7	15.8	22.3	29.5	39.2	63.7
NO_x, (Saltzman) (ppm)	19.2	24.6	31.2	42.1	52.5	75.9
Smoke Index	1.5	4.3	4.3	10.2	19.8	31.0

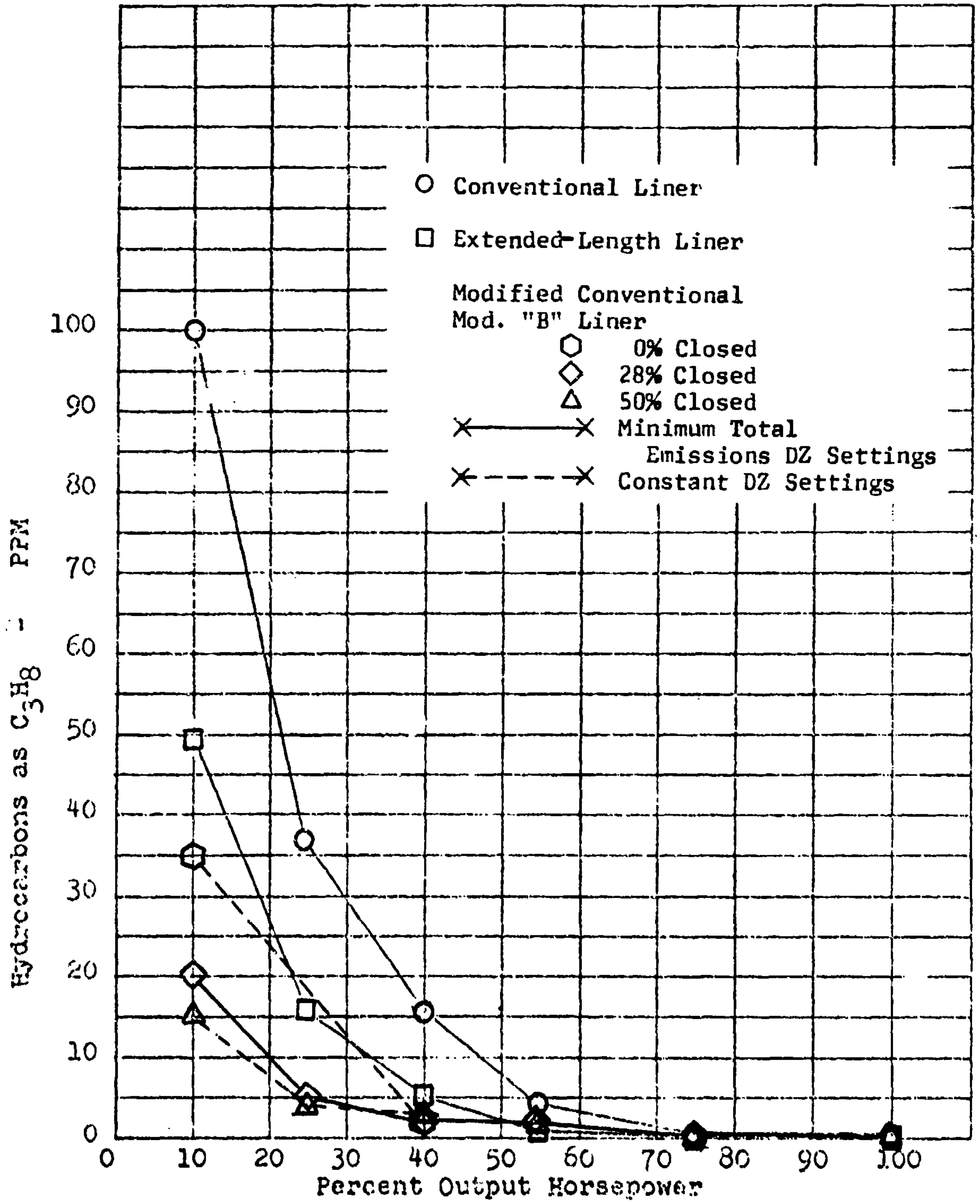

Figure 412. Nonregenerative T63-A-5A Combustor Hydrocarbon Emission Data Comparison for Standard-Length, Modified Conventional, Modification "B" Combustor and T63 Baseline Combustors.

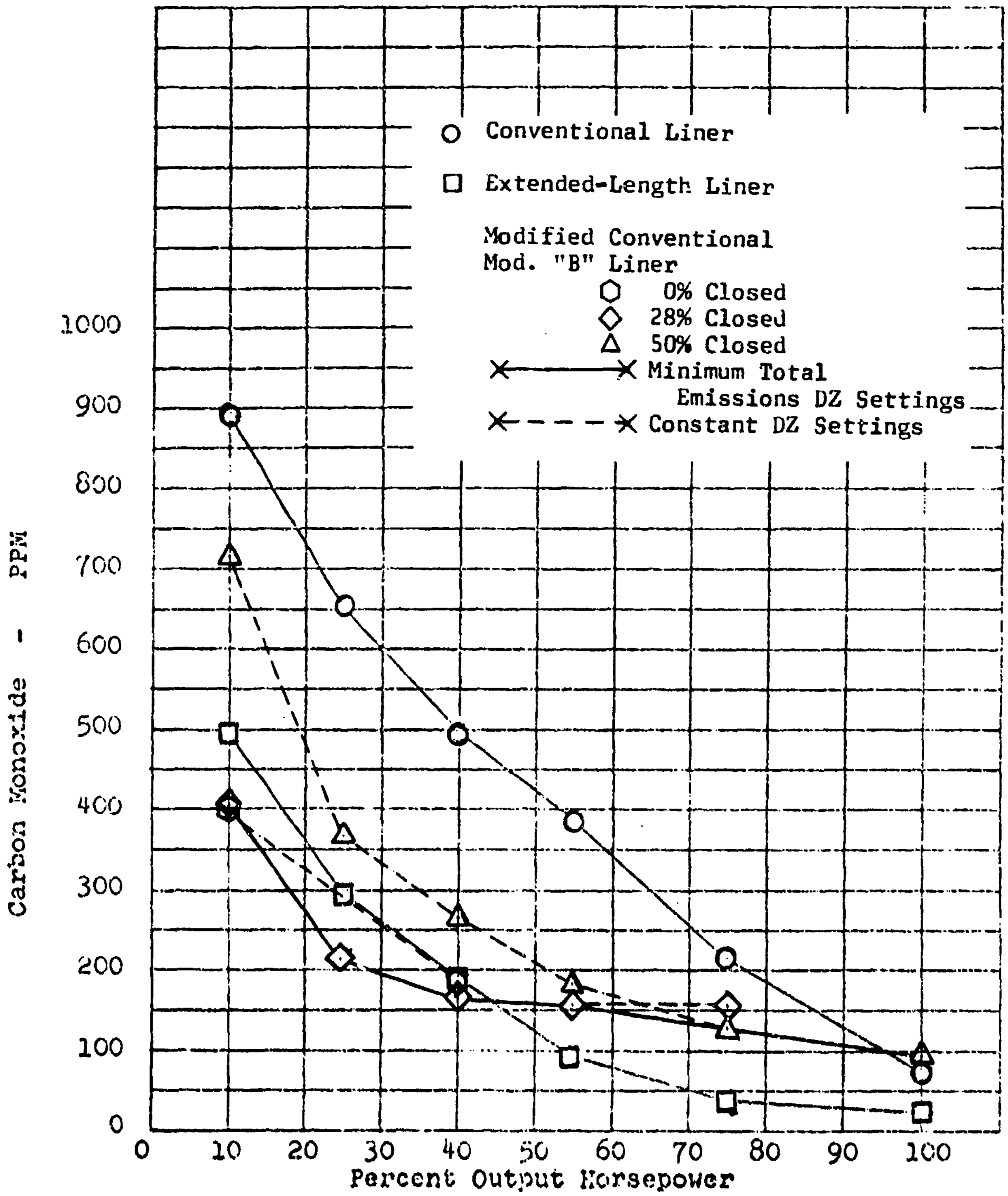

Figure 413. **Nonregenerative T63-A-5A Combustor Carbon Monoxide Emission Data Comparison for Standard-Length, Modified Conventional Modification "B" Combustor and T63 Baseline Combustors.**

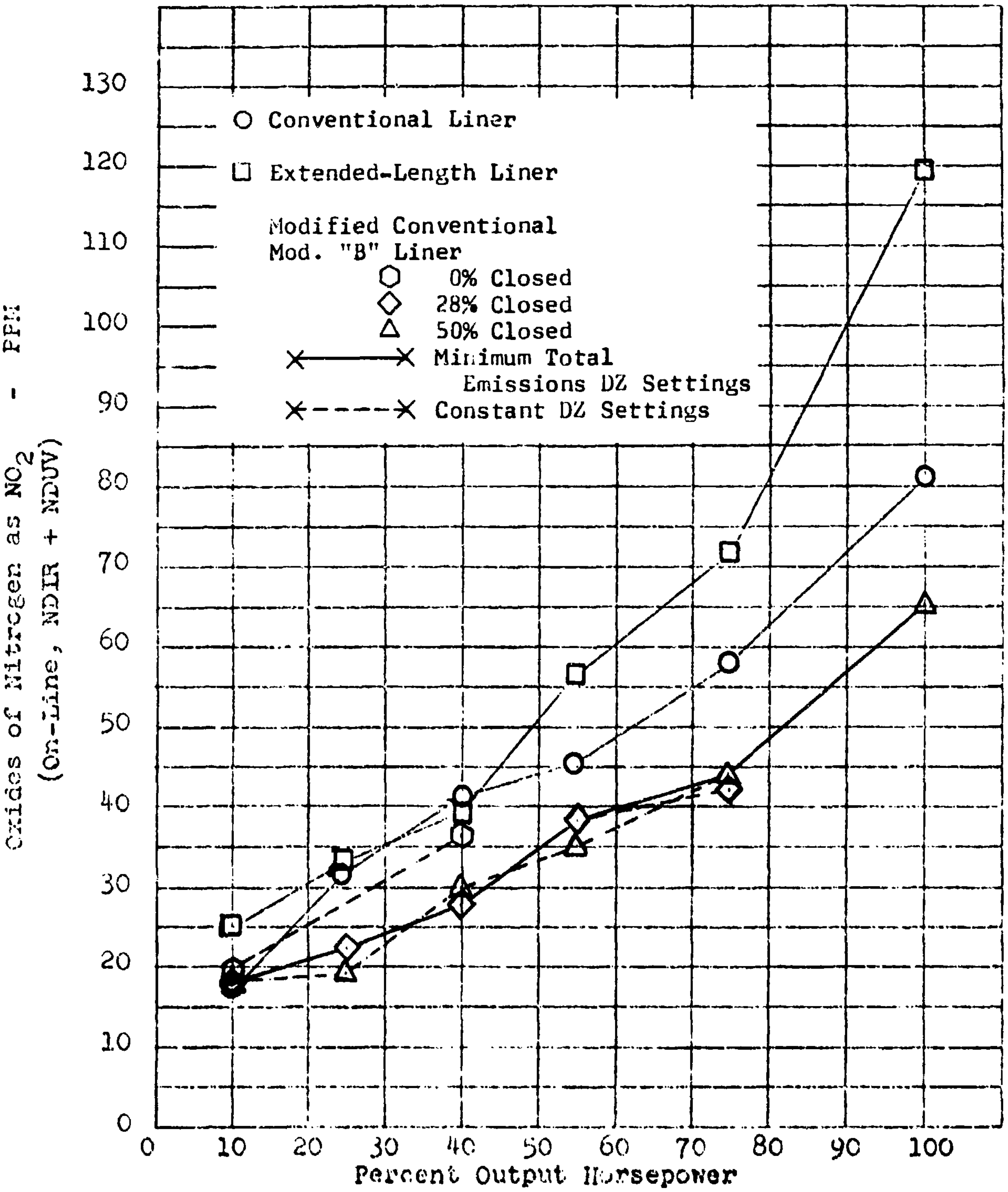

Figure 414. Nonregenerative T63-A-5A Combustor Nitrogen Oxides Emission Data Comparison for Standard-Length, Modified Conventional, Modification "B" Combustor and T63 Baseline Combustors.

nitrogen oxide concentrations for both 28% and 50% closed settings were quite similar and well below the conventional combustor level. Modification "B" reduced NO_x by 20% over the duty cycle. The CO vs NO_x tradeoff curves in Figure 415 illustrate that both CO and NO_x concentrations have been reduced. A decrease in one emission has not been obtained by simply changing the combustor operating conditions to increase the other constituent.

The greatest effect of changes in the dilution geometry was obtained in the smoke number readings; see Figure 416. Even though the airblast fuel injector greatly reduced the smoke, particulates were increased by 25%, over the LOH duty cycle, when compared to the original Conventional T63-A-5A baseline smoke measurements. When compared to the second baseline retest smoke measurements, the Modification "B" Final Modified Conventional reduced the smoke/particulates by 73%.

The total mass emissions for the "Final Design Modified Conventional Modification "B" Combustor Liner," was 51% below the total emissions from the Conventional T63-A-5A combustor liner. A summary of the emission performance for each configuration of the Modified Conventional combustor liner is given in Table LXXXVII. Even though Modification "B" did not produce the total reduction of the initial design, it was able to reduce hydrocarbons, carbon monoxide, and nitrogen oxide simultaneously.

Summaries of the exhaust temperature profiles for the Conventional T63 combustor liner, the Extended-Length combustor liner, and the Final Modified Conventional Modification "B" combustor liner are compared in Table LXXXVIII and Figure 417. The temperature profile for the 50% closed geometry setting was the best of the Final Combustors tested. Even at maximum power conditions, the worst profile measured for the 50% closed setting, the T_{max}/T_{avg} value was only 1.145.

Following the nonregenerative combustor conditions testing, the Modified Conventional Modification "B" combustor liner was tested at regenerative engine conditions. Four different dilution geometry settings were used during these tests: 0%, 28%, 50%, and 71% closed. The test data sheets for the fifteen data points taken are presented in Figures 418 through 432. The emissions data from these operating points are summarized in Table LXXXIX. Using variable geometry, the Modification "B" combustor liner was able to maintain carbon monoxide at 80.8 ppm at idle and to limit the nitrogen oxide production to 78.1 ppm at takeoff power conditions. A comparison of LOH duty cycle emissions for both the Conventional T63-A-5A and the Modified Conventional Modification "B" combustor liner is given in Table XC. The average cycle fuel-consumption rate for a nonregenerative engine is 140.65 lb/hr, and for a regenerative engine the fuel rate is 97.64 lb/hr. Therefore, on a total mass basis, the

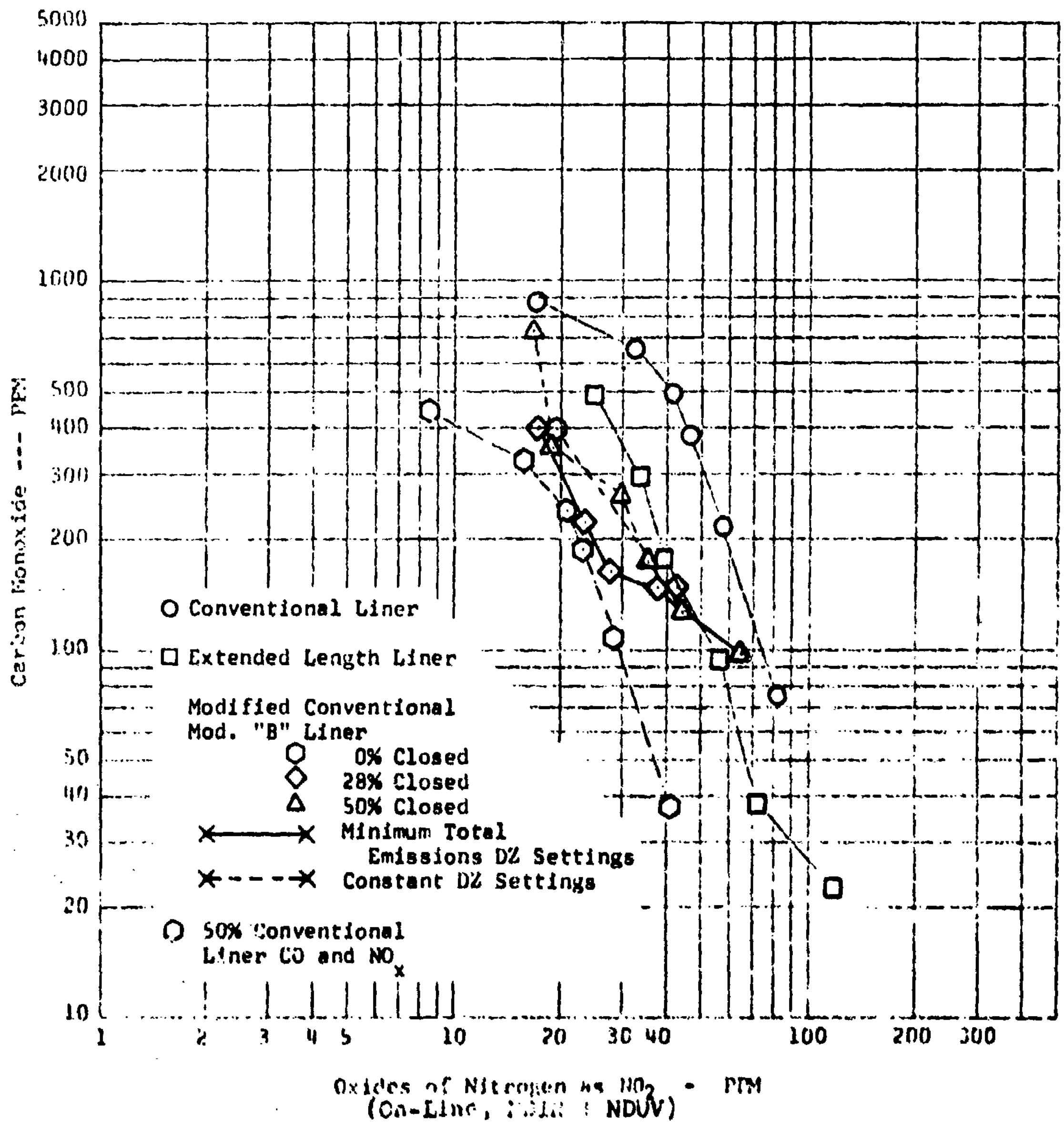

Figure 415. Nonregenerative T63-A-5A Combustor Carbon Monoxide VS Nitrogen Oxides Emission Data Comparison for Standard-Length, Modified Conventional, Modification "B" Combustor and T63 Baseline Combustors.

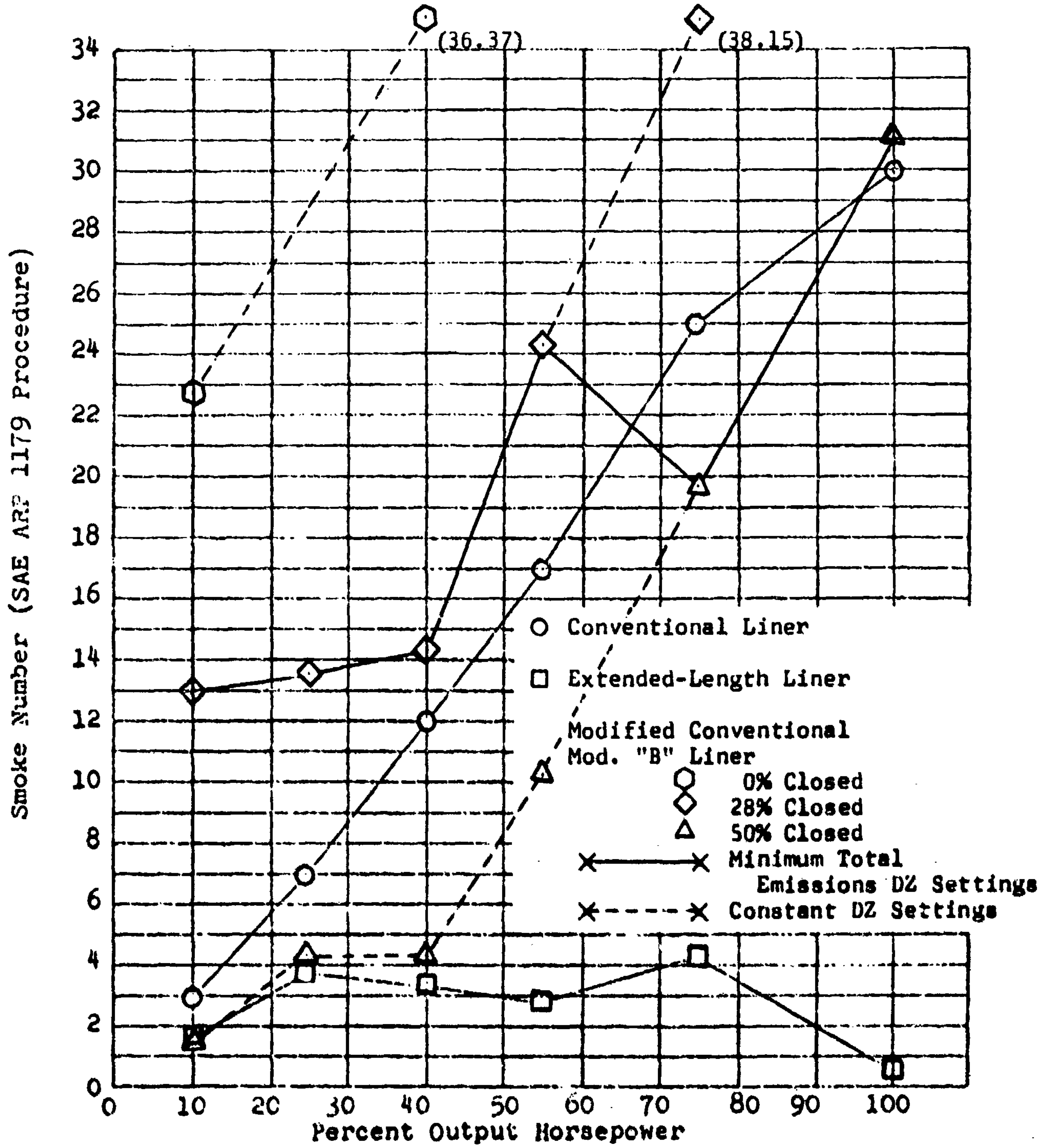

Figure 416. Nonregenerative T63-A-5A Combustor Smoke Data Comparison for Standard-Length, Modified Conventional, Modification "B" Combustor and T63 Baseline Combustors.

TABLE LXXXVII. EMISSION INDEX SUMMARY FOR T63 BASELINE AND FINAL MODIFIED CONVENTIONAL COMBUSTOR

Combustor Tested	C_xH_y	CO	NO_x	Particu-lates	Total Emissions
EMISSION INDEX (lb /1000 lb fuel)					
• Baseline	1.544	26.094	5.068	.239	32.945
• Final Modified Conventional					
Initial Design	.161	6.878	5.970	.438	13.447
Modification "A"	.500	15.966	4.499	3.471	24.436
Modification "B"	.364	11.432	4.068	.298	16.162
RELATIVE EMISSION INDEX (%)					
• Baseline	100	100	100	100	100
• Final Modified Conventional					
Initial Design	10	26	118	183	41
Modification "A"	32	61	87	1452	74
Modification "B"	24	44	80	125	49

TABLE LXXXVIII. COMPARISON OF EXHAUST TEMPERATURE PROFILE (T_{max}/T_{avg}) OF FINAL DESIGN MODIFIED CONVENTIONAL COMBUSTOR LINER MODIFICATION "B" AND BASELINE COMBUSTOR LINERS AT T63 NONREGENERATIVE CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional T63-A-5A Liner	1.115	1.142	1.120	1.113	1.104	1.065
II. Extended Length Liner	1.229	1.210	1.198	1.171	1.129	1.188
III. Final Design Modified Conventional Liner Mod. "B"						
0% Closed	1.224		1.154			
28% Closed	1.192	1.231	1.268	1.295	1.318	
50% Closed	1.127	1.131	1.115	1.128	1.139	1.145

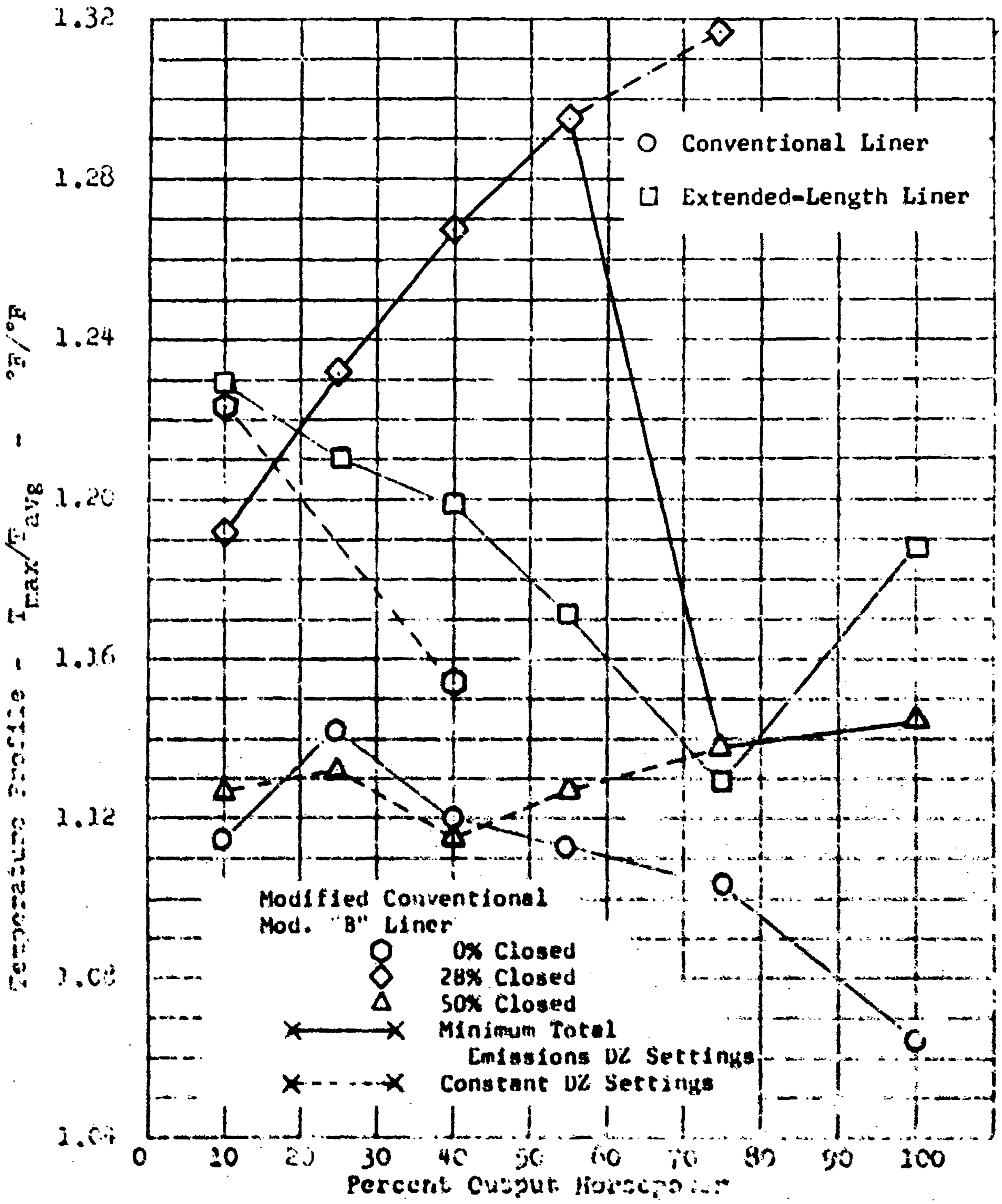

Figure 417. Nonregenerative T63-A-5A Combustor Temperature Profile Data Comparison for Standard-Length, Modified Conventional, Modification "B" Combustor and T63 Baseline Combustors.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 07, READING #    961
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE:  8-17-72                      READING WAS TAKEN AT 14:21:29 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY    0 % CLOSED       10 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         1.763 LB/SEC    AVG BURNER INLET TEMP   569. DEG F
AVG BURNER INLET PRES  43.7    PSIA     AVG BURNER OUTLET TEMP 1137. DEG F
AVG BURNER DELTA P      5.21    "HG     PRESSURE LOSS            5.86 %
OVERALL F/A RATIO     .00810  (F/M)     FUEL FLOW RATE          51.43 LB/HR
AIR LOAD FACTOR        1.3566           PATTERN FACTOR         .34365
BOT HOT SPOT:  # 36 = 1338.  DEG F      MAX BOT / AVG BOT      1.1463
FUEL INLET TEMPERATURE  98.  DEG F      FUEL INLET PRESSURE     55.1  PSIA
HEAT LOADING PARAMETER  .25534E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1181.  6 1244. 15 1112. 19 1080. 24 1139. 27 1203. 36 1338.
ANNULUS 2   4 1208.  7 1252. 16 1090. 21 1073. 25 1100. 34 1307. 37 1381.
ANNULUS 3   5 1160. 14 1042. 17 1001. 22 1057. 26 1144. 35 1222. 39 1189.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE            43.65    PSIA    TOTAL PRESSURE          43.67   PSIA
STATIC PRESSURE           43.31    PSIA    STATIC PRESSURE         43.33   PSIA
VELOCITY DELTA P            .70     "HG    VELOCITY DELTA P          .70    "HG
AIR TEMPERATURE            670.  DEG F     AIR TEMPERATURE          669.  DEG F
AIR VELOCITY            174.95 FT/SEC      AIR VELOCITY          175.51 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            -.033    "HG

AIR FLOW DATA: P-REF= 104.0 PSIA   DELTA P= 1.47 "HG   T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      191.      HZ    VOLUMETRIC FLOW RATE   8.32 GAL/HR
FUEL PRESSURE AT F/M  260.1     PSIA    FUEL TEMP AT F/M        95.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   41.10 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            41.95 PSIA (XDUCER = 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               5.10  "HG (XDUCER = 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2    1.378 %     O2  19.000 %     CO     90.0 PPM     CHX      1.2 PPM
 NO     28.2 PPM  NO2      3.1 PPM  NOX    31.3 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=    9.71                  CHX=    .23
               CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=    6.10

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .007530
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7140 %
   CHECK ON F/A RATIO- F/A = .007689 W/O O2, CALCULATED O2 = 18.790 %

SMOKE INDEX: 7.12
SALTZMAN NOX = 30.0                  PPM
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Figure 418. Final Modified Conventional Liner, Modification "B" at Regenerative 10% Power - 0% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 78, TEST SERIES 87, READING #    962
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE: 8-17-72                         READING WAS TAKEN AT 1440: 4 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY  28 % CLOSED       10 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1,782 LB/SEC     AVG BURNER INLET TEMP    668. DEG F
AVG BURNER INLET PRES   43,8    PSIA      AVG BURNER OUTLET TEMP 1168. DEG F
AVG BURNER DELTA P       6,40    "HG      PRESSURE LOSS              7,17 %
OVERALL F/A RATIO       ,00805  (F/M)     FUEL FLOW RATE            51,61 LB/HR
AIR LOAD FACTOR         1,3647            PATTERN FACTOR            ,35165
BOT HOT SPOT:  # 34 = 1333,  DEG F        MAX BOT / AVG BOT         1,1491
FUEL INLET TEMPERATURE 101,  DEG F        FUEL INLET PRESSURE        54,8  PSIA
HEAT LOADING PARAMETER  ,25519E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1167.  6 1220. 15 1168. 19 1109. 24 1132. 27 1183. 36 1309.
ANNULUS 2  4 1193.  7 1219. 16 1125. 21 1068. 25 1130. 34 1333. 37 1244.
ANNULUS 3  5 1154. 14 1057. 17 1323. 22 1054. 26 1109. 35 1219. 39 1137.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          43,84   PSIA     TOTAL PRESSURE         43,84   PSIA
STATIC PRESSURE         43,55   PSIA     STATIC PRESSURE        43,47   PSIA
VELOCITY DELTA P          ,59    "HG     VELOCITY DELTA P         ,74    "HG
AIR TEMPERATURE          660.  DEG F     AIR TEMPERATURE         660.  DEG F
AIR VELOCITY          161,80 FT/SEC      AIR VELOCITY          180,10 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          ,007    "HG

AIR FLOW DATA: P-REF= 104,0 PSIA   DELTA P= 1,50 "HG    T-REF= 100, DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       192,      HZ    VOLUMETRIC FLOW RATE    8,30 GAL/HR
FUEL PRESSURE AT F/M   263,1    PSIA     FUEL TEMP AT F/M          90,  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     40,70 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              42,07 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 0,40  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    1,978 %     O2  18,750 %     CO    104,0 PPM     CHX      1,0 PPM
 NO     10,0 PPM  NO2      0,0 PPM  NOX    15,0 PPM (NO(NDIR) + NO2(NDUV))
 NO       ,0 PPM  NO2       ,0 PPM  NOX      ,0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12,71                  CHX=     ,30
                  CHEMILUMINESCENCE NOX=    ,00,    NDIR + NDUV NOX=   5,13

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       ,007636
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99,6427 %
   CHECK ON F/A RATIO- F/A = ,007621 W/O O2, CALCULATED O2 = 18,794 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 28.0               PPM
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Figure 419. Final Modified Conventional Liner, Modification "B" at Regenerative 10% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING #    963
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE: 8-17-72                       READING WAS TAKEN AT 1504:38 HOURS

CYCLE POINT  1    VARIABLE GEOMETRY  50 % CLOSED       10 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.785 LB/SEC    AVG BURNER INLET TEMP   667. DEG F
AVG BURNER INLET PRES   43.6    PSIA     AVG BURNER OUTLET TEMP 1162. DEG F
AVG BURNER DELTA P       9.07    "HG     PRESSURE LOSS           10.22 %
OVERALL F/A RATIO       .00802  (F/M)    FUEL FLOW RATE          51.55 LB/HR
AIR LOAD FACTOR         1.3753           PATTERN FACTOR         .15246
BOT HOT SPOT:  # 27 = 1242.  DEG F       MAX BOT / AVG BOT      1.0691
FUEL INLET TEMPERATURE 103.  DEG F       FUEL INLET PRESSURE      52.7  PSIA
HEAT LOADING PARAMETER  .25644E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1185.  6 1240. 15 1143. 19 1149. 24 1200. 27 1242. 36 1241.
ANNULUS 2   4 1228.  7 1240. 16 1116. 21 1105. 25 1195. 34 1233. 37 1179.
ANNULUS 3   5 1164. 14 1017. 17 1027. 22 1101. 26 1159. 35 1122. 39 1117.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           43.56   PSIA    TOTAL PRESSURE           43.60   PSIA
STATIC PRESSURE          43.25   PSIA    STATIC PRESSURE          43.28   PSIA
VELOCITY DELTA P           .62    "HG    VELOCITY DELTA P           .64    "HG
AIR TEMPERATURE          668.   DEG F    AIR TEMPERATURE          667.   DEG F
AIR VELOCITY            165.58 FT/SEC    AIR VELOCITY            167.50 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))      -.081      "HG

AIR FLOW DATA: P-REF= 104.7 PSIA   DELTA P= 1.50 "HG    T-REF= 105. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       192.      HZ    VOLUMETRIC FLOW RATE     8.36 GAL/HR
FUEL PRESSURE AT F/M   267.7    PSIA     FUEL TEMP AT F/M         100.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   39.12 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             41.28 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                9.03  "HG (XDUCER # 10)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    1.616 %     O2  18.500 %     CO    205.1 PPM     CHX      1.3 PPM
 NO     10.6 PPM  NO2      6.0 PPM  NOX     13.6 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM  NO2       .0 PPM  NOX       .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  24.92                  CHX=     .25
                  CHEMILUMINESCENCE NOX=     .00,   NDIR + NDUV NOX=   3.31

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .007936
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.3819 %
   CHECK ON F/A RATIO- F/A = .007849 W/O O2, CALCULATED O2 = 18.733 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 23.7                     PPM
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Figure 420. Final Modified Conventional Liner, Modification "B" at Regenerative 10% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING #    964
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE: 8-17-72                    READING WAS TAKEN AT 1532:33 HOURS

CYCLE POINT  6    VARIABLE GEOMETRY  28 % CLOSED      25 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.031 LB/SEC    AVG BURNER INLET TEMP   781. DEG F
AVG BURNER INLET PRES   50.4    PSIA     AVG BURNER OUTLET TEMP 1237. DEG F
AVG BURNER DELTA P       7.48   "HG      PRESSURE LOSS            7.29 %
OVERALL F/A RATIO       .00870  (F/M)    FUEL FLOW RATE          63.57 LB/HR
AIR LOAD FACTOR         1.3717           PATTERN FACTOR          .36256
BOT HOT SPOT: # 34 = 1432.  DEG F        MAX BOT / AVG BOT       1.1572
FUEL INLET TEMPERATURE 104.  DEG F       FUEL INLET PRESSURE      69.4   PSIA
HEAT LOADING PARAMETER  .27325E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1243.  6 1293. 15 1252. 19 1181. 24 1210. 27 1279. 36 1385.
ANNULUS 2   4 1263.  7 1295. 16 1283. 21 1137. 25 1213. 34 1432. 37 1314.
ANNULUS 3   5 1229. 14 1137. 17 1094. 22 1123. 26 1192. 35 1318. 39 1191.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          50.43   PSIA    TOTAL PRESSURE          50.44   PSIA
STATIC PRESSURE         50.04   PSIA    STATIC PRESSURE         50.06   PSIA
VELOCITY DELTA P          .79   "HG     VELOCITY DELTA P          .79   "HG
AIR TEMPERATURE          781.   DEG F   AIR TEMPERATURE          780.   DEG F
AIR VELOCITY           176.20 FT/SEC    AIR VELOCITY           175.15 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.038   "HG

AIR FLOW DATA: P-REF= 104.2 PSIA   DELTA P= 1.97 "HG   T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       237.     HZ     VOLUMETRIC FLOW RATE  10.32 GAL/HR
FUEL PRESSURE AT F/M   258.6    PSIA     FUEL TEMP AT F/M       102.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   46.76 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            48.38 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               7.48 "HG  (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    1.649 %     O2  18.509 %     CO     75.6 PPM     CHX      1.2 PPM
 NO     25.3 PPM   NO2     7.2 PPM  NOX    32.6 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2      .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   8.49               CHX=      .22
                    CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   6.00

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .008821
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7387 %
   CHECK ON F/A RATIO- F/A = .007946 W/O O2, CALCULATED O2 = 18.697 %

SMOKE INDEX: 0.01
SALTZMAN NOX = 31.5               PPM
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Figure 421. Final Modified Conventional Liner, Modification "B" at Regenerative 25% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 87, READING #    965
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS,
TEST DATE: 8-17-72                        READING WAS TAKEN AT 155441 HOURS

CYCLE POINT  6    VARIABLE GEOMETRY   0 X CLOSED       25 X POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.022 LB/SEC     AVG BURNER INLET TEMP   708. DEG F
AVG BURNER INLET PRES  58.7    PSIA      AVG BURNER OUTLET TEMP 1251. DEG F
AVG BURNER DELTA P      5.89    "HG      PRESSURE LOSS              5.71 %
OVERALL F/A RATIO      .00876  (F/M)     FUEL FLOW RATE            63.80 LB/HR
AIR LOAD FACTOR        1.3595            PATTERN FACTOR            .27336
BOT HOT SPOT: # 36 = 1402.  DEG F        MAX BOT / AVG BOT        1.1204
FUEL INLET TEMPERATURE 105.  DEG F       FUEL INLET PRESSURE        70.7  PSIA
HEAT LOADING PARAMETER  .27301E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1265,  6 1349, 15 1195, 19 1165, 24 1238, 27 1299, 36 1402.
ANNULUS 2   4 1273,  7 1342, 16 1186, 21 1152, 25 1259, 34 1373, 37 1364.
ANNULUS 3   5 1255, 14 1127, 17 1091, 22 1143, 26 1247, 35 1297, 39 1249.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE          58.65    PSIA    TOTAL PRESSURE          50.66   PSIA
STATIC PRESSURE         58.23    PSIA    STATIC PRESSURE         50.24   PSIA
VELOCITY DELTA P         .81     "HG     VELOCITY DELTA P          .86   "HG
AIR TEMPERATURE         700.   DEG F     AIR TEMPERATURE          700.  DEG F
AIR VELOCITY           178.07 FT/SEC     AIR VELOCITY            182.78 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.019    "HG

AIR FLOW DATA: P-REF= 104.1 PSIA   DELTA P= 1.95 "HG   T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY     238.       HZ     VOLUMETRIC FLOW RATE  10.36 GAL/HR
FUEL PRESSURE AT F/M  329.1     PSIA     FUEL TEMP AT F/M       103.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    47.76 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             48.72 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                5.88 "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    1.721 %     O2  18.500 %     CO     67.3 PPM     CHX      1.0 PPM
 NO     28.1 PPM  NO2      3.1 PPM  NOX    36.2 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   7.49                CHX=    .18
                  CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   6.62

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .008321
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7730 %
   CHECK ON F/A RATIO- F/A = .008253 W/O O2, CALCULATED O2 = 18.598 %

SMOKE INDEX: 3.27
SALTZMAN NOX = 39.3              PPM
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Figure 422. Final Modified Conventional Liner, Modification "B", at Regenerative 25% Power - 0% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING #    966
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE: 8-17-72                          READING WAS TAKEN AT 1618:42 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY   0 % CLOSED      40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW           2.408 LB/SEC    AVG BURNER INLET TEMP     716. DEG F
AVG BURNER INLET PRES   60.1    PSIA     AVG BURNER OUTLET TEMP   1319. DEG F
AVG BURNER DELTA P       7.92    "HG     PRESSURE LOSS               5.74 %
OVERALL F/A RATIO       .00951  (F/M)    FUEL FLOW RATE             82.44 LB/HR
AIR LOAD FACTOR         1.3742           PATTERN FACTOR             .28642
BOT HOT SPOT:  # 36 = 1492.  DEG F       MAX BOT / AVG BOT          1.1308
FUEL INLET TEMPERATURE 107.  DEG F       FUEL INLET PRESSURE         97.8  PSIA
HEAT LOADING PARAMETER   .29740E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1    2 1340.  6 1406. 15 1256. 19 1213. 24 1290. 27 1356. 36 1492.
ANNULUS 2    4 1344.  7 1412. 16 1246. 21 1206. 25 1318. 34 1455. 37 1461.
ANNULUS 3    5 1330. 14 1190. 17 1138. 22 1193. 26 1310. 35 1413. 39 1332.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE          60.06    PSIA    TOTAL PRESSURE            60.12   PSIA
STATIC PRESSURE         59.61    PSIA    STATIC PRESSURE           59.64   PSIA
VELOCITY DELTA P          .91     "HG    VELOCITY DELTA P            .99    "HG
AIR TEMPERATURE          717.   DEG F    AIR TEMPERATURE            716.  DEG F
AIR VELOCITY           173.85 FT/SEC     AIR VELOCITY             181.66 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]            -.134    "HG

AIR FLOW DATA: P-REF= 103.4 PSIA   DELTA P= 2.79 "HG    T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      387.      HZ     VOLUMETRIC FLOW RATE    13.40 GAL/HR
FUEL PRESSURE AT F/M  332.1   PSIA       FUEL TEMP AT F/M         103.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     56.64 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              57.89 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 6.95 "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    1.817 %      O2   18.400 %     CO      65.2 PPM     CHX      1.0 PPM
NO      32.3 PPM   NO2      8.1 PPM  NOX      40.4 PPM [NO(NDIR) + NO2(NDUV)]
NO        .0 PPM   NO2       .0 PPM  NOX        .0 PPM [ CHEMILUMINESCENCE  ]
EMISSIONS INDEX, LB/1000 LB FUEL: CO=   6.69                   CHX=      .16
               CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=       6.81

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .008764
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7876 %
   CHECK ON F/A RATIO= F/A = .008738 W/O O2, CALCULATED O2 = 18.464 %

SMOKE INDEX: 7.73
SALTZMAN NOX = 44.0            PPM
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Figure 423. Final Modified Conventional Liner, Modification "B" at Regenerative 40% Power - 0% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 87, READING #    967
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE:  8-17-72                       READING WAS TAKEN AT 1631:59 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  28 % CLOSED       40 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.425 LB/SEC    AVG BURNER INLET TEMP    715. DEG F
AVG BURNER INLET PRES   60.1    PSIA     AVG BURNER OUTLET TEMP 1299. DEG F
AVG BURNER DELTA P       8.95    "HG     PRESSURE LOSS             7.31 %
OVERALL F/A RATIO      .00938   (F/M)    FUEL FLOW RATE           81.87 LB/HR
AIR LOAD FACTOR         1.3823           PATTERN FACTOR          .36036
BOT HOT SPOT:  # 34 = 1509.  DEG F       MAX BOT / AVG BOT      1.1619
FUEL INLET TEMPERATURE 107.  DEG F       FUEL INLET PRESSURE      95.9  PSIA
HEAT LOADING PARAMETER  .29511E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1318.  6 1365. 15 1289. 19 1218. 24 1263. 27 1331. 36 1470.
ANNULUS 2   4 1336.  7 1371. 16 1243. 21 1179. 25 1274. 34 1509. 37 1396.
ANNULUS 3   5 1302. 14 1180. 17 1129. 22 1166. 26 1257. 35 1420. 39 1258.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           60.16    PSIA    TOTAL PRESSURE          60.12    PSIA
STATIC PRESSURE          59.70    PSIA    STATIC PRESSURE         59.63    PSIA
VELOCITY DELTA P           .93     "HG    VELOCITY DELTA P         1.00     "HG
AIR TEMPERATURE           716.  DEG F     AIR TEMPERATURE          715.  DEG F
AIR VELOCITY            175.40 FT/SEC     AIR VELOCITY           182.29 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            .080     "HG

AIR FLOW DATA: P-REF= 103.3 PSIA   DELTA P= 2.83 "HG    T-REF= 106. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       305.      HZ     VOLUMETRIC FLOW RATE  13.31 GAL/HR
FUEL PRESSURE AT F/M   330.2    PSIA      FUEL TEMP AT F/M        104.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   55.75 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            57.64 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               8.99  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
            18.50%  GAS SAMPLES TAKEN IN PLANE #1
CO2    1.673 %     O2  [illegible] %     CO     62.0 PPM     CHX      1.3 PPM
 NO     28.1 PPM  NO2     6.8 PPM  NOX     35.0 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2      .0 PPM  NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   6.45                  CHX=    .21
                 CHEMILUMINESCENCE NOX=    .00,   NOIR + NDUV NOX=   5.98

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       [illegible]
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7767 %
   CHECK ON F/A RATIO- F/A = .008053 W/O O2, CALCULATED O2 = 18.665 %

SMOKE INDEX: 1.30
SALTZMAN NOX = 33.3                PPM
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REMARKS: O2 INPUT ERROR
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Figure 424. Final Modified Conventional Liner, Modification "B" at Regenerative 40% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING #    968
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS,
TEST DATE: 8-17-72                     READING WAS TAKEN AT 1647:18 HOURS

CYCLE POINT  5    VARIABLE GEOMETRY  50 % CLOSED      40 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.428 LB/SEC    AVG BURNER INLET TEMP    714. DEG F
AVG BURNER INLET PRES   60.1    PSIA     AVG BURNER OUTLET TEMP 1306. DEG F
AVG BURNER DELTA P      12.46    "HG     PRESSURE LOSS            10.18 %
OVERALL F/A RATIO       .00946  (F/M)    FUEL FLOW RATE           82.65 LB/HR
AIR LOAD FACTOR         1.3835           PATTERN FACTOR          .16600
BOT HOT SPOT:  # 36 = 1405.  DEG F       MAX BOT / AVG BOT       1.0752
FUEL INLET TEMPERATURE 109.  DEG F       FUEL INLET PRESSURE      94.3   PSIA
HEAT LOADING PARAMETER  .29794E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1362.  6 1402. 15 1277. 19 1283. 24 1334. 27 1383. 36 1405.
ANNULUS 2   4 1389.  7 1398. 16 1248. 21 1230. 25 1334. 34 1390. 37 1328.
ANNULUS 3   5 1330. 14 1140. 17 1151. 22 1220. 26 1304. 35 1286. 39 1243.

LEFT SIDE          *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          60.14    PSIA    TOTAL PRESSURE         60.14    PSIA
STATIC PRESSURE         59.67    PSIA    STATIC PRESSURE        59.61    PSIA
VELOCITY DELTA P          .95     "HG    VELOCITY DELTA P        1.07     "HG
AIR TEMPERATURE          715.   DEG F    AIR TEMPERATURE         714.   DEG F
AIR VELOCITY           177.53 FT/SEC     AIR VELOCITY          188.38 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          .006     "HG

AIR FLOW DATA: P-REF= 103.4 PSIA   DELTA P= 2.83 "HG   T-REF= 104. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       308.      HZ    VOLUMETRIC FLOW RATE  13.44 GAL/HR
FUEL PRESSURE AT F/M   333.6     PSIA    FUEL TEMP AT F/M        105.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    54.02 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             57.08 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               12.46  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2   1.841 %     O2   18.180 %     CO    119.9 PPM     CHX       .2 PPM
 NO    25.3 PPM  NO2      8.1 PPM  NOX     33.4 PPM [NO(NDIR) + NO2(NDUV)]
 NO      .0 PPM  NO2       .0 PPM  NOX       .0 PPM [ CHEMILUMINESCENCE  ]
  EMISSIONS INDEX, LB/1000 LB FUEL: CO=  12.38                CHX=     .03
                 CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=   5.66

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .009615
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.6749 %
   CHECK ON F/A RATIO- F/A = .008876 W/O O2, CALCULATED O2 = 18.426 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 32.6                PPM
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Figure 425. Final Modified Conventional Liner, Modification "B" at Regenerative 40% Power - 50% Closed DZ.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING # 970
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS,
TEST DATE: 8-17-72 READING WAS TAKEN AT 1721:22 HOURS

CYCLE POINT 4 VARIABLE GEOMETRY 50 % CLOSED 55 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW 2.636 LB/SEC AVG BURNER INLET TEMP 764. DEG F
AVG BURNER INLET PRES 65.6 PSIA AVG BURNER OUTLET TEMP 1410. DEG F
AVG BURNER DELTA P 14.04 "HG PRESSURE LOSS 10.51 %
OVERALL F/A RATIO .01057 (F/M) FUEL FLOW RATE 100.29 LB/HR
AIR LOAD FACTOR 1.4065 PATTERN FACTOR .17045
BOT HOT SPOT: # 6 = 1520. DEG F MAX BOT / AVG BOT 1.0781
FUEL INLET TEMPERATURE 108. DEG F FUEL INLET PRESSURE 122.1 PSIA
HEAT LOADING PARAMETER .33159E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1484.	6	1520.	15	1381.	19	1382.	24	1443.	27	1482.	36	1511.
ANNULUS 2	4	1514.	7	1520.	16	1349.	21	1338.	25	1435.	34	1494.	37	1408.
ANNULUS 3	5	1439.	14	1241.	17	1236.	22	1329.	26	1405.	35	1385.	39	1317.

LEFT SIDE *** AIR INLET TUBE CONDITIONS *** RIGHT SIDE
TOTAL PRESSURE 65.56 PSIA TOTAL PRESSURE 65.57 PSIA
STATIC PRESSURE 65.01 PSIA STATIC PRESSURE 65.08 PSIA
VELOCITY DELTA P 1.12 "HG VELOCITY DELTA P 1.00 "HG
AIR TEMPERATURE 764. DEG F AIR TEMPERATURE 764. DEG F
AIR VELOCITY 188.10 FT/SEC AIR VELOCITY 178.03 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)] -.023 "HG

AIR FLOW DATA: P-REF= 103.1 PSIA DELTA P= 3.32 "HG T-REF= 99. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY 373. HZ VOLUMETRIC FLOW RATE 16.31 GAL/HR
FUEL PRESSURE AT F/M 323.7 PSIA FUEL TEMP AT F/M 105. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 58.57 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 62.10 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 14.02 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 1.961 % O2 17.000 % CO 94.5 PPM CHX 1.1 PPM
NO 33.7 PPM NO2 7.2 PPM NOX 41.8 PPM [NO(NDIR) + NO2(NDUV)]
NO .0 PPM NO2 .0 PPM NOX .0 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 9.73 CHX= .16
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 6.22

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .009648
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.7326 %
CHECK ON F/A RATIO- F/A = .009438 W/O O2, CALCULATED O2 = 18.260 %

SMOKE INDEX: 0.02
SALTZMAN NOX = 43.3 PPM

Figure 426. Final Modified Conventional Liner, Modification "B", at Regenerative 55% Power - 50% Closed DZ.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 8/, READING # 971
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS,
TEST DATE: 8-17-72 READING WAS TAKEN AT 1745:13 HOURS

CYCLE POINT 4 VARIABLE GEOMETRY 28 % CLOSED 55 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	2.631 LB/SEC	AVG BURNER INLET TEMP	764. DEG F
AVG BURNER INLET PRES	65.9 PSIA	AVG BURNER OUTLET TEMP	1412. DEG F
AVG BURNER DELTA P	10.00 "HG	PRESSURE LOSS	7.46 %
OVERALL F/A RATIO	.01073 (F/M)	FUEL FLOW RATE	101.61 LB/HR
AIR LOAD FACTOR	1.3974	PATTERN FACTOR	.35382
BOT HOT SPOT: # 34 = 1641. DEG F		MAX BOT / AVG BOT	1.1623
FUEL INLET TEMPERATURE 109. DEG F		FUEL INLET PRESSURE	127.7 PSIA

HEAT LOADING PARAMETER .33440E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	1445.	6	1493.	15	1408.	19	1327.	24	1377.	27	1449.	36	1584.
ANNULUS 2	4	1458.	7	1564.	16	1353.	21	1289.	25	1386.	34	1641.	37	1486.
ANNULUS 3	5	1430.	14	1299.	17	1222.	22	1277.	26	1367.	35	1516.	39	1338.

LEFT SIDE *** AIR INLET TUBE CONDITIONS *** RIGHT SIDE

TOTAL PRESSURE	65.89 PSIA	TOTAL PRESSURE	65.85 PSIA
STATIC PRESSURE	65.31 PSIA	STATIC PRESSURE	65.33 PSIA
VELOCITY DELTA P	1.18 "HG	VELOCITY DELTA P	1.05 "HG
AIR TEMPERATURE	764. DEG F	AIR TEMPERATURE	764. DEG F
AIR VELOCITY	192.91 FT/SEC	AIR VELOCITY	181.87 FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) .075 "HG

AIR FLOW DATA: P-REF= 103.4 PSIA DELTA P= 3.29 "HG T-REF= 98. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	378. HZ	VOLUMETRIC FLOW RATE	16.53 GAL/HR
FUEL PRESSURE AT F/M	322.4 PSIA	FUEL TEMP AT F/M	105. DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 60.96 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 63.01 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE 10.04 "HG (XDUCER # 13)

* CHEMICAL ANALYSIS RESULTS *
GAS SAMPLES TAKEN IN PLANE #1

CO2 1.865 % O2 17.700 % CO 51.8 PPM CHX .3 PPM
NO 35.2 PPM NO2 6.8 PPM NOX 42.0 PPM (NO(NDIR) + NO2(NDUV))
NO .0 PPM NO2 .0 PPM NOX .0 PPM (CHEMILUMINESCENCE)
EMISSIONS INDEX, LB/1000 LB FUEL: CO= 4.72 CHX= .04
CHEMILUMINESCENCE NOX= .00, NDIR + NDUV NOX= 6.20

CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS: .009264
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS: 99.0365 %
CHECK ON F/A RATIO- F/A = .008959 W/O O2, CALCULATED O2 = 18.390 %

SMOKE INDEX: 3.60
SALTZMAN NOX = 49.6 PPM

Figure 427. Final Modified Conventional Liner, Modification "B", at Regenerative 55% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING #     972
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE:  8-17-72                        READING WAS TAKEN AT 1815:59 HOURS

CYCLE POINT  3    VARIABLE GEOMETRY  28 % CLOSED       75 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.794 LB/SEC     AVG BURNER INLET TEMP    841. DEG F
AVG BURNER INLET PRES  75.6     PSIA      AVG BURNER OUTLET TEMP  1559. DEG F
AVG BURNER DELTA P      10.56     "HG     PRESSURE LOSS              6.86 %
OVERALL F/A RATIO       .01214   (F/M)    FUEL FLOW RATE           122.18 LB/HR
AIR LOAD FACTOR         1.3338            PATTERN FACTOR            .33181
BOT HOT SPOT:  # 34 = 1797.  DEG F        MAX BOT / AVG BOT        1.1525
FUEL INLET TEMPERATURE 109.  DEG F        FUEL INLET PRESSURE      167.9  PSIA
HEAT LOADING PARAMETER  .35012E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1599.  6 1639. 15 1558. 19 1463. 24 1526. 27 1615. 36 1728.
ANNULUS 2   4 1607.  7 1644. 16 1495. 21 1427. 25 1546. 34 1797. 37 1633.
ANNULUS 3   5 1573. 14 1445. 17 1350. 22 1410. 26 1526. 35 1690. 39 1474.

LEFT SIDE               *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE            75.59    PSIA    TOTAL PRESSURE         75.61   PSIA
STATIC PRESSURE           75.05    PSIA    STATIC PRESSURE        75.22   PSIA
VELOCITY DELTA P           1.09     "HG    VELOCITY DELTA P         .79    "HG
AIR TEMPERATURE           841.    DEG F    AIR TEMPERATURE         841.   DEG F
AIR VELOCITY             178.19 FT/SEC     AIR VELOCITY          151.40 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            -.043   "HG

AIR FLOW DATA: P-REF= 103.0 PSIA   DELTA P= 3.72 "HG    T-REF=  96. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        454.      HZ     VOLUMETRIC FLOW RATE  19.88 GAL/HR
FUEL PRESSURE AT F/M   318.2    PSIA       FUEL TEMP AT F/M       107.   DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   70.41 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            72.59 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE              10.53  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    2.083 %      O2  17.400 %      CO     42.3 PPM     CHX      .2 PPM
 NO     57.9 PPM   NO2      6.4 PPM   NOX    64.3 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2       .0 PPM   NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   3.41                   CHX=     .03
                   CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   8.52

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010325
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.9604 %
   CHECK ON F/A RATIO- F/A = .009987 W/O O2, CALCULATED O2 = 18.095 %

SMOKE INDEX: 8.18
SALTZMAN NOX = 66.1                  PPM
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Figure 428. Final Modified Conventional Liner, Modification "B" at Regenerative 75% Power - 28% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 87, READING #    973
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS,
TEST DATE:  8-17-72                          READING WAS TAKEN AT 1833:10 HOURS

CYCLE POINT  3    VARIABLE GEOMETRY  50 % CLOSED        75 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.791 LB/SEC     AVG BURNER INLET TEMP    839. DEG F
AVG BURNER INLET PRES  75.6     PSIA      AVG BURNER OUTLET TEMP 1509. DEG F
AVG BURNER DELTA P     14.56     "HG      PRESSURE LOSS              9.47 %
OVERALL F/A RATIO      .01215  (F/M)      FUEL FLOW RATE           122.06 LB/HR
AIR LOAD FACTOR        1.3312             PATTERN FACTOR           .15305
BOT HOT SPOT:  # 36 = 1680.  DEG F        MAX BOT / AVG BOT        1.0712
FUEL INLET TEMPERATURE 109.  DEG F        FUEL INLET PRESSURE     165.0  PSIA
HEAT LOADING PARAMETER  .35016E+07 BTU/HOUR/ATM/CUBIC FOOT

                    **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1647.  6 1676. 15 1531. 19 1529. 24 1596. 27 1646. 36 1680.
ANNULUS 2   4 1679.  7 1680. 16 1496. 21 1482. 25 1588. 34 1662. 37 1592.
ANNULUS 3   5 1606. 14 1372. 17 1375. 22 1469. 26 1552. 35 1553. 39 1535.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE           75.58    PSIA    TOTAL PRESSURE           75.55   PSIA
STATIC PRESSURE          74.02    PSIA    STATIC PRESSURE          74.94   PSIA
VELOCITY DELTA P          1.54     "HG    VELOCITY DELTA P          1.24    "HG
AIR TEMPERATURE          839.  DEG F      AIR TEMPERATURE          839.  DEG F
AIR VELOCITY            212.00 FT/SEC     AIR VELOCITY            190.34 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            .040    "HG

AIR FLOW DATA: P-REF= 102.9 PSIA   DELTA P= 3.71 "HG    T-REF=  85. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       434.       HZ    VOLUMETRIC FLOW RATE  19.00 GAL/HR
FUEL PRESSURE AT F/M  306.9    PSIA       FUEL TEMP AT F/M          107.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    68.41 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              71.99 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                14.59  "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                       GAS SAMPLES TAKEN IN PLANE #1
CO2    2.303 %      O2  17.600 %      CO     44.4 PPM      CHX       .0 PPM
 NO     53.6 PPM   NO2      6.0 PPM   NOX     59.6 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM   NO2       .0 PPM   NOX       .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   3.90                   CHX=      .01
                   CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=    7.09

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .011450
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8746 %
   CHECK ON F/A RATIO- F/A = .011030 W/O O2, CALCULATED O2 = 17.700 %

SMOKE INDEX: 0.01
SALTZMAN NOX = 65.9                  PPM
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Figure 429. Final Modified Conventional Liner, Modification "B" at Regenerative 75% Power - 50% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 07, READING #    074
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE: 8-17-72                     READING WAS TAKEN AT 1049:30 HOURS

CYCLE POINT  3    VARIABLE GEOMETRY  71 % CLOSED       75 % POWER SETTING

                 ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.033 LB/SEC    AVG BURNER INLET TEMP   840. DEG F
AVG BURNER INLET PRES  75.6    PSIA      AVG BURNER OUTLET TEMP 1536. DEG F
AVG BURNER DELTA P     20.00    "HG      PRESSURE LOSS            12.99 %
OVERALL F/A RATIO      .01199  (F/M)     FUEL FLOW RATE          122.30 LB/HR
AIR LOAD FACTOR        1.3598            PATTERN FACTOR          .35384
BOT HOT SPOT:  #  6 = 1782.  DEG F       MAX BOT / AVG BOT       1.1603
FUEL INLET TEMPERATURE 110.  DEG F       FUEL INLET PRESSURE     161.0  PSIA
HEAT LOADING PARAMETER  .35059E+07 BTU/HOUR/ATM/CUBIC FOOT

               **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2 1669.  6 1782. 15 1506. 19 1542. 24 1607. 27 1649. 36 1656.
ANNULUS 2  4 1741.  7 1740. 16 1435. 21 1430. 25 1565. 34 1579. 37 1430.
ANNULUS 3  5 1583. 14 1200. 17 1203. 22 1404. 26 1530. 35 1471. 30 1340.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE           75.50   PSIA    TOTAL PRESSURE         75.66   PSIA
STATIC PRESSURE          75.01   PSIA    STATIC PRESSURE        75.13   PSIA
VELOCITY DELTA P          1.17    "HG    VELOCITY DELTA P        1.07    "HG
AIR TEMPERATURE          841.   DEG F    AIR TEMPERATURE        840.   DEG F
AIR VELOCITY            184.07 FT/SEC    AIR VELOCITY           176.00 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.151    "HG

AIR FLOW DATA: P-REF= 103.1 PSIA   DELTA P= 3.01 "HG   T-REF=  94. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       455.      HZ    VOLUMETRIC FLOW RATE  19.92 GAL/HR
FUEL PRESSURE AT F/M   300.0    PSIA     FUEL TEMP AT F/M         100.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   65.79 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE                 71.12 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   19.93  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   2.107 %     O2  17.100 %       CO    73.1 PPM      CHX     1.9 PPM
 NO    38.7 PPM  NO2     7.6 PPM   NOX    46.3 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM  NO2      .0 PPM   NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   9.06                    CHX=    .12
                 CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   6.21

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .010807
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7989 %
   CHECK ON F/A RATIO- F/A = .010110 W/O O2, CALCULATED O2 = 16.000 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 40.7                PPM
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Figure 430. Final Modified Conventional Liner, Modification "B" at Regenerative 75% Power - 71% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 87, READING #    975
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE:  8-17-72                      READING WAS TAKEN AT 1015:57 HOURS

CYCLE POINT  2    VARIABLE GEOMETRY  71 % CLOSED      100 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         3.006 LB/SEC    AVG BURNER INLET TEMP   970. DEG F
AVG BURNER INLET PRES  84.9    PSIA     AVG BURNER OUTLET TEMP 1749. DEG F
AVG BURNER DELTA P     22.96    "HG     PRESSURE LOSS           13.30 %
OVERALL F/A RATIO      .01416  (F/M)    FUEL FLOW RATE         153.26 LB/HR
AIR LOAD FACTOR        1.3368           PATTERN FACTOR          .35925
BOT HOT SPOT:  #  6 = 2029.  DEG F      MAX BOT / AVG BOT      1.1600
FUEL INLET TEMPERATURE 109.  DEG F      FUEL INLET PRESSURE     226.0  PSIA
HEAT LOADING PARAMETER  .39140E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1889.  6 2029. 15 1727. 19 1771. 24 1821. 27 1883. 36 1877.
ANNULUS 2   4 1969.  7 1976. 16 1659. 21 1629. 25 1779. 34 1797. 37 1600.
ANNULUS 3   5 1798. 14 1497. 17 1477. 22 1595. 26 1738. 35 1682. 39 1541.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          84.85   PSIA   TOTAL PRESSURE          84.92   PSIA
STATIC PRESSURE         84.30   PSIA   STATIC PRESSURE         84.22   PSIA
VELOCITY DELTA P         1.10    "HG   VELOCITY DELTA P         1.42    "HG
AIR TEMPERATURE         971.  DEG F    AIR TEMPERATURE         969.  DEG F
AIR VELOCITY           177.61 FT/SEC   AIR VELOCITY           201.43 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))       -.102    "HG

AIR FLOW DATA: P-REF= 102.7 PSIA   DELTA P= 4.30 "HG   T-REF=  93. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       971.      HZ    VOLUMETRIC FLOW RATE  24.90 GAL/HR
FUEL PRESSURE AT F/M  293.2    PSIA    FUEL TEMP AT F/M         100.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    73.60 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             70.93 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               22.99  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    2.690 %      O2  16.400 %     CO      24.1 PPM     CHX      .2 PPM
 NO     74.1 PPM  NO2      4.0 PPM  NOX      78.1 PPM (NO(NDIR) + NO2(NDUV))
 NO       .0 PPM  NO2       .0 PPM  NOX        .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   1.67                   CHX=     .02
                 CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=    8.80

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .013223
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.9138 %
   CHECK ON F/A RATIO= F/A = .012650 W/O O2, CALCULATED O2 = 17.306 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 8.20                PPM
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Figure 431. Final Modified Conventional Liner, Modification "B" at Regenerative 100% Power - 71% Closed DZ.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 07, READING #    970
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN REGEN T63 INLET CONDITIONS.
TEST DATE: 8-17-72                      READING WAS TAKEN AT 1927:39 HOURS

CYCLE POINT  2    VARIABLE GEOMETRY  50 % CLOSED      100 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW           2.993 LB/SEC    AVG BURNER INLET TEMP    971. DEG F
AVG BURNER INLET PRES   85.0    PSIA     AVG BURNER OUTLET TEMP 1784. DEG F
AVG BURNER DELTA P      15.76    "HG     PRESSURE LOSS               9.11 %
OVERALL F/A RATIO      .01420  (F/M)     FUEL FLOW RATE            152.07 LB/HR
AIR LOAD FACTOR        1.3310            PATTERN FACTOR             .17375
BOT HOT SPOT:  # 36 = 1926.  DEG F       MAX BOT / AVG BOT         1.0792
FUEL INLET TEMPERATURE 109.  DEG F       FUEL INLET PRESSURE      230.9  PSIA
HEAT LOADING PARAMETER  .39007E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1876.  6 1901. 15 1736. 19 1737. 24 1806. 27 1893. 36 1926.
ANNULUS 2   4 1903.  7 1906. 16 1703. 21 1603. 25 1800. 34 1903. 37 1795.
ANNULUS 3   5 1630. 14 1601. 17 1571. 22 1662. 28 1705. 35 1773. 39 1672.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          84.99   PSIA    TOTAL PRESSURE          85.03   PSIA
STATIC PRESSURE         84.25   PSIA    STATIC PRESSURE         84.45   PSIA
VELOCITY DELTA P         1.51    "HG    VELOCITY DELTA P         1.19    "HG
AIR TEMPERATURE         971.  DEG F     AIR TEMPERATURE         971.  DEG F
AIR VELOCITY          207.70 FT/SEC     AIR VELOCITY          184.02 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.000    "HG

AIR FLOW DATA: P-REF= 102.7 PSIA   DELTA P= 4.26 "HG   T-REF=  93. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      570.      HZ    VOLUMETRIC FLOW RATE  24.03 GAL/HR
FUEL PRESSURE AT F/M  294.2     PSIA    FUEL TEMP AT F/M        109.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    77.27 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             81.02 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               15.72  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                    GAS SAMPLES TAKEN IN PLANE #1
CO2   2.820 %     O2  16.500 %     CO     20.0 PPM    CHX       .2 PPM
 NO    88.0 PPM  NO2      4.4 PPM  NOX    93.0 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   1.77                  CHX=    .02
                 CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=  10.86

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .012033
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8074 %
   CHECK ON F/A RATIO- F/A = .012072 W/O O2, CALCULATED O2 = 17.478 %

SMOKE INDEX: 2.67
SALTZMAN NOX = 96.7                  PPM
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Figure 432. Final Modified Conventional Liner, Modification "B" at Regenerative 100% Power - 50% Closed DZ.

TABLE LXXXIX. EMISSION DATA OF FINAL DESIGN MODIFIED CONVENTIONAL COMBUSTOR LINER MODIFICATION "B" OPERATING AT T63 REGENERATIVE COMBUSTOR CONDITIONS

Dilution Zone Variable Geometry Setting	Cycle Point 1	6	5	4	3	2
0% Closed						
CO, (ppm)	80.8	67.3	65.2			
C_xH_y, (ppm)	1.2	1.0	1.0			
NO_x, (NDIR & NDUV) (ppm)	31.3	36.2	40.4			
NO_x, (Saltzman) (ppm)	30.0	39.3	44.0			
Smoke Index	7.1	3.3	7.7			
28% Closed						
CO, (ppm)	104.9	75.6	62.0	51.8	42.5	
C_xH_y, (ppm)	1.6	1.2	1.3	.3	.2	
NO_x, (NDIR & NDUV) (ppm)	[illegible]5.8	32.6	[illegible]	42.0	64.3	
NO_x, (Saltzman) (ppm)	[illegible]8.0	31.5	33.3	49.6	66.1	
Smoke Index	.0	.0	1.3	3.6	8.2	
50% Closed						
CO, (ppm)	[illegible]05.1		119.9	94.5	44.4	25.6
C_xH_y, (ppm)	1.3		.2	1.1	.0	.2
NO_x, (NDIR & NDUV) (ppm)	16.6		33.4	[illegible]1.0	59.6	[illegible]3.0
NO_x, (Saltzman) (ppm)	23.7		32.6	43.3	65.9	96.7
Smoke Index	.0		.0	.0	.0	2.7
71% Closed						
CO, (ppm)					73.1	24.1
C_xH_y, (ppm)					1.0	.2
NO_x, (NDIR & NDUV) (ppm)					46.3	79.1
NO_x, (Saltzman) (ppm)					48.7	83.0
Smoke Index					.0	.0

TABLE XC. EMISSION INDEX COMPARISON OF CONVENTIONAL T63-A-5A COMBUSTOR AND THE FINAL MODIFIED CONVENTIONAL MODIFICATION "B" COMBUSTOR

EMISSION CONSTITUENT	EMISSION INDEX (LB/1000 LB FUEL) NONREGENERATIVE BASELINE T63-A-5A	MODIFIED CONVENTIONAL	REGENERATIVE BASELINE T63-A-5A	MODIFIED CONVENTIONAL
C_xH_y	1.544	.364	.378	.072
CO	26.094	11.432	13.804	5.009
NO_x	5.068	4.068	8.412	6.725
PARTICULATES	.239	.298	.040	.030
TOTAL	32.945	16.162	22.634	11.836

Conventional T63-A-5A combustor produces 0.713 lb/hr of NO_x at non-regenerative conditions while the Modified Conventional combustor produces 0.656 lb/hr of NO_x at regenerative conditions. Per hour of engine operation, this is an 8% reduction of NO_x from the Modified Conventional combustor liner.

Pressure loss for the Modification "B" combustor liner is compared with losses for the Conventional T63-A-5A combustor liner and Regenerative T63 combustor liner in Table XCI. The Modified Conventional combustor losses at the 0% closed dilution geometry setting are nearly equal to the Regenerative liner losses. At the 28% closed dilution geometry setting, the Modification "B" losses compare very favorably with the Conventional T63-A-5A losses. A large penalty in pressure loss was suffered at the 50% and 71% closed dilution settings.

Regenerative conditions exhaust temperature profile data are presented in Table XCII. The 50% closed dilution setting in the Modified Conventional combustor liner produced temperature profiles comparable to both the Conventional T63-A-5A liner and the Regenerative T63 liner when tested at regenerative combustor conditions.

For the ambient temperature and pressure startup test, the standard T63 spark igniter was used, as it had been in all previous testing of the Modified Conventional combustors. The rig test conditions were:

Airflow Rate, W_a	=	0.24 lb/sec
Inlet Temperature, BIT	=	86°F
Inlet Pressure, BIP	=	14.5 psia
Fuel/Air Ratio, F/A	=	.038 and .029
Fuel Flow Rate, W_f	=	32 and 25 lb/hr

The dilution-zone geometry was set to 28% closed. The prefire rig and combustor conditions are given in Figure 433. The 32 lb/hr fuel flow rate was set, and fire-up was achieved 10 seconds after the spark igniter was activated. The rig and combustor conditions after fire-up are given in Figure 434. A second fire-up test was performed at the 25 lb/hr fuel flow rate. Ignition was achieved at this fuel flow, also 10 seconds after activation of the spark igniter. These post fire-up conditions are presented in Figure 435.

Emission/combustor data were obtained for the "Final Modified Conventional Modification "B" Combustor Liner" operating at the 50% closed dilution geometry setting for a nine-point set of parametric combustor conditions. Three values of four parameters were set on the combustor, the middle value of the three being the nominal test

TABLE XCI. COMPARISON OF COMBUSTOR PRESSURE LOSS (%) FOR FINAL DESIGN MODIFIED CONVENTIONAL MODIFICATION "B" COMBUSTOR LINER AND BASELINE T63 COMBUSTOR LINERS AT T63 REGENERATIVE OPERATING CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional T63-A-5A Liner	6.50	6.52	7.00	6.85	6.27	6.64
II. Regenerative T63 Liner	5.59	5.50	5.45	5.31	5.20	5.21
III. Final Design Modified Conventional Liner Mod. "B"						
0% Closed	5.86	5.71	5.74			
28% Closed	7.17	7.29	7.31	7.46	6.86	
50% Closed	10.22		10.18	10.51	9.47	9.11
71% Closed					12.99	13.30

TABLE XCII. COMPARISON OF EXHAUST TEMPERATURE PROFILE (T_{max}/T_{avg}) FOR FINAL DESIGN MODIFIED CONVENTIONAL COMBUSTOR LINER MODIFICATION "B" AND BASELINE T63 COMBUSTOR LINERS OPERATING AT T63 REGENERATIVE CONDITIONS

	Cycle Point					
	1	6	5	4	3	2
I. Conventional T63-A-5A Liner	1.076	1.085	1.078	1.063	1.065	1.051
II. Regenerative T63 Liner	1.090	1.112	1.114	1.120	1.130	1.147
III. Final Design Modified Conventional Liner Mod. "B"						
0% Closed	1.146	1.120	1.131			
28% Closed	1.149	1.157	1.162	1.162	1.152	
50% Closed	1.069		1.075	1.078	1.071	1.079
71% Closed					1.160	1.160

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T63 COMBUSTOR EXPERIMENTS - RIG 8/U 70, TEST SERIES 86, READING #    958
T3 MODIFIED CONVENTIONAL LINER, MOD "B"  AMBIENT IGNITION TEST.
TEST DATE: 8-17-72                         READING WAS TAKEN AT 1327:13 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  28 % CLOSED        0 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          .240 LB/SEC    AVG BURNER INLET TEMP     86. DEG F
AVG BURNER INLET PRES  14.4    PSIA     AVG BURNER OUTLET TEMP    87. DEG F
AVG BURNER DELTA P        .18    "HG    PRESSURE LOSS            .60 %
OVERALL F/A RATIO     .00000  (F/M)     FUEL FLOW RATE           .00 LB/HR
AIR LOAD FACTOR         .3884           PATTERN FACTOR        .72657
BOT HOT SPOT:  #  5 =   88.  DEG F      MAX BOT / AVG BOT     1.0092
FUEL INLET TEMPERATURE  93.  DEG F      FUEL INLET PRESSURE     13.9  PSIA
HEAT LOADING PARAMETER  .00000E+00 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1  2   88.  6   87. 15   87. 19   86. 24   87. 27   87. 36   87.
ANNULUS 2  4   87.  7   87. 16   87. 21   87. 25   87. 34   87. 37   87.
ANNULUS 3  5   88. 14   86. 17   87. 22   87. 26   87. 35   88. 39   88.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          14.45   PSIA    TOTAL PRESSURE          14.45  PSIA
STATIC PRESSURE         14.43   PSIA    STATIC PRESSURE         14.44  PSIA
VELOCITY DELTA P          .03    "HG    VELOCITY DELTA P          .01   "HG
AIR TEMPERATURE           86.  DEG F    AIR TEMPERATURE           86.  DEG F
AIR VELOCITY            41.08 FT/SEC    AIR VELOCITY            38.51 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]         -.006   "HG

AIR FLOW DATA: P-REF= 109.8 PSIA   DELTA P=  .35 "HG   T-REF= 108. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY          .      HZ   VOLUMETRIC FLOW RATE     .00 GAL/HR
FUEL PRESSURE AT F/M   14.7    PSIA     FUEL TEMP AT F/M         93.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   14.36 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            14.48 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                .17  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX = X                     PPM
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Figure 433. Final Modified Conventional Liner, Modification "B" Startup Test - Prefire Conditions.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 86, READING #    959
T63 MODIFIED CONVENTIONAL LINER, MOD "B"  AMBIENT IGNITION TEST.
TEST DATE: 8-17-72                        READING WAS TAKEN AT 1328:48 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  28 % CLOSED        0 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          .235 LB/SEC    AVG BURNER INLET TEMP     86. DEG F
AVG BURNER INLET PRES  14.5    PSIA     AVG BURNER OUTLET TEMP   903. DEG F
AVG BURNER DELTA P        .18    "HG    PRESSURE LOSS             .61 %
OVERALL F/A RATIO      .03814  (F/M)    FUEL FLOW RATE          32.24 LB/HR
AIR LOAD FACTOR         .3778           PATTERN FACTOR         .89581
BOT HOT SPOT:  # 34 = 1633.  DEG F      MAX BOT / AVG BOT      1.8096
FUEL INLET TEMPERATURE  93.  DEG F      FUEL INLET PRESSURE      20.4   PSIA
HEAT LOADING PARAMETER  .48138E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2  693.  6  909. 15 1624. 19 1077. 24  937. 27 1282. 36 1296.
ANNULUS 2   4  828.  7  905. 16 1207. 21  650. 25  856. 34 1633. 37  840.
ANNULUS 3   5  505. 14  912. 17  473. 22  485. 26  635. 35  842. 39  445.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE         14.52   PSIA     TOTAL PRESSURE         14.52   PSIA
STATIC PRESSURE        14.52   PSIA     STATIC PRESSURE        14.51   PSIA
VELOCITY DELTA P        -.01    "HG     VELOCITY DELTA P         .03    "HG
AIR TEMPERATURE          86.  DEG F     AIR TEMPERATURE          86.  DEG F
AIR VELOCITY            .00 FT/SEC      AIR VELOCITY           42.55 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))       -.013    "HG

AIR FLOW DATA: P-REF= 109.8 PSIA    DELTA P=  .33 "HG    T-REF= 107. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      118.      HZ    VOLUMETRIC FLOW RATE    5.20 GAL/HR
FUEL PRESSURE AT F/M  148.6    PSIA     FUEL TEMP AT F/M         91.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    14.43 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             14.60 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 .17  "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX = X                PPM
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Figure 434. Final Modified Conventional Liner, Modification "B" Startup Test - Fire-up at .038 F/A.

T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 86, READING # 960
T63 MODIFIED CONVENTIONAL LINER, MOD "B" AMBIENT IGNITION TEST.
TEST DATE: 8-17-72 READING WAS TAKEN AT 1333:15 HOURS

CYCLE POINT 7 VARIABLE GEOMETRY 28 % CLOSED 0 % POWER SETTING

***** EXPERIMENTAL CONDITIONS *****

BURNER AIR FLOW	.230	LB/SEC	AVG BURNER INLET TEMP	87.	DEG F
AVG BURNER INLET PRES	14.5	PSIA	AVG BURNER OUTLET TEMP	593.	DEG F
AVG BURNER DELTA P	.25	"HG	PRESSURE LOSS	.85	%
OVERALL F/A RATIO	.02882	(F/M)	FUEL FLOW RATE	24.74	LB/HR
AIR LOAD FACTOR	.3845		PATTERN FACTOR	.94828	
BOT HOT SPOT: # 15 =	1074.	DEG F	MAX BOT / AVG BOT	1.8100	
FUEL INLET TEMPERATURE	93.	DEG F	FUEL INLET PRESSURE	17.7	PSIA

HEAT LOADING PARAMETER .37003E+07 BTU/HOUR/ATM/CUBIC FOOT

**** BURNER OUTLET TEMPERATURE SURVEY ****

	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP	ID	TEMP
ANNULUS 1	2	369.	6	560.	15	1074.	19	779.	24	722.	27	792.	36	858.
ANNULUS 2	4	596.	7	542.	16	829.	21	374.	25	621.	34	1048.	37	346.
ANNULUS 3	5	316.	14	548.	17	253.	22	360.	26	428.	35	523.	39	.

LEFT SIDE *** AIR INLET TUBE CONDITIONS *** RIGHT SIDE

TOTAL PRESSURE	14.49	PSIA	TOTAL PRESSURE	14.49	PSIA
STATIC PRESSURE	14.47	PSIA	STATIC PRESSURE	14.48	PSIA
VELOCITY DELTA P	.04	"HG	VELOCITY DELTA P	.03	"HG
AIR TEMPERATURE	86.	DEG F	AIR TEMPERATURE	87.	DEG F
AIR VELOCITY	52.01	FT/SEC	AIR VELOCITY	41.51	FT/SEC

DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL)) .002 "HG

AIR FLOW DATA: P-REF= 110.1 PSIA DELTA P= .34 "HG T-REF= 107. DEG F

FUEL SYSTEM DATA:

FUEL F/M FREQUENCY	89.	HZ	VOLUMETRIC FLOW RATE	3.99	GAL/HR
FUEL PRESSURE AT F/M	150.2	PSIA	FUEL TEMP AT F/M	91.	DEG F

** MISCELLANEOUS TRANSDUCER READINGS **

MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE 14.37 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE 14.50 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE .25 "HG (XDUCER # 13)

SMOKE INDEX: X
SALTZMAN NOX =X PPM

Figure 435. Final Modified Conventional Liner, Modification "B" Startup Test - Fire-up at .029 F/A.

value. The parametric point values tested were the following:

Airflow Rate, W_a (lb/sec)	1	2	3
Inlet Temperature, BIT (°F)	200	600	1000
Inlet Pressure, BIP (psia)	30	60	90
Exhaust Temperature, BOT (°F)	1100	1500	1900

The 50% closed dilution geometry setting was used throughout the parametric tests because the best exhaust temperature profiles were obtained using that setting. The detailed test results from the parametric tests are presented in Figures 436 through 444. Important data from these test results are summarized in Table XCIII.

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T63 COMBUSTION EXPERIMENTS - RIG B/U 70, TEST SERIES 88, READING #    977
T63 MODIFIED CONVENTIONAL LINER, MOD "B"  RUN PARAMETRIC STUDIES.
TEST DATE:  4-18-72                        READING WAS TAKEN AT 123813! HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  50 % CLOSED         0 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.689 LB/SEC     AVG BURNER INLET TEMP   200. DEG F
AVG BURNER INLET PRES  59.7    PSIA      AVG BURNER OUTLET TEMP 1501. DEG F
AVG BURNER DELTA P      4.73    "HG      PRESSURE LOSS              3.89 %
OVERALL F/A RATIO      .01488  (F/A)     FUEL FLOW RATE           143.78 LB/HR
AIR LOAD FACTOR         .8836            PATTERN FACTOR           .17958
HOT HOT SPOT: # 36 = 1734.  DEG F        MAX BOT / AVG BOT        1.1556
FUEL INLET TEMPERATURE   98.  DEG F      FUEL INLET PRESSURE       196.4  PSIA
HEAT LOADING PARAMETER  .5217RE+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1617.  6 1627. 15 1526. 19 1586. 24 1569. 27 1636. 36 1734.
ANNULUS 2   4 1555.  7 1645. 16 1453. 21 1352. 25 1581. 34 1873. 37 1617.
ANNULUS 3   5 1498. 14 1204. 17 1131. 22 1312. 26 1589. 35 1342. 39 1484.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***          RIGHT SIDE
TOTAL PRESSURE          59.73    PSIA     TOTAL PRESSURE          59.75   PSIA
STATIC PRESSURE         59.55    PSIA     STATIC PRESSURE         59.59   PSIA
VELOCITY DELTA P          .37    "HG      VELOCITY DELTA P          .32    "HG
AIR TEMPERATURE          209.  DEG F      AIR TEMPERATURE          200.  DEG F
AIR VELOCITY            83.83 FT/SEC      AIR VELOCITY            77.01 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.038    "HG

AIR FLOW DATA: P-REF= 184.8 PSIA   DELTA P=27.54 "HG   T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      532.       HZ     VOLUMETRIC FLOW RATE  23.29 GAL/HR
FUEL PRESSURE AT F/M  324.4     PSIA      FUEL TEMP AT F/M           88.  DEG F

                ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   57.41 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE              58.88 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                 4.71  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    4.150 %     O2  15.208 %      CO    370.0 PPM     CHX      3.0 PPM
 NO    13.4 PPM  NO2     20.4 PPM  NOX    33.8 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM  NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  18.65                    CHX=    .23
                   CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=   2.78

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .019812
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.3429 %
   CHECK ON F/A RATIO- F/A = .019402 W/O C2. CALCULATED O2 = 15.321 %

SMOKE INDEX: 12.00
SALTZMAN NOX = 42.5                  PPM
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Figure 436. Final Modified Conventional Liner Modification "B" Parametric Test at BIT = 200°F.

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T63 COMBUSTOR EXPERIMENTS - RIG E/U 78, TEST SERIES 68, READING #    978
T63 MODIFIED CONVENTIONAL LINER, MOD "B" FOR PARAMETRIC STUDIES.
TEST DATE: [illegible]-18-72                       READING WAS TAKEN AT 1312158 HOURS

CYCLE POINT  7     VARIABLE GEOMETRY  50 % CLOSED        0 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.[illegible] LB/SEC    AVG BURNER INLET TEMP   680. DEG F
AVG BURNER INLET PRESS  60.[illegible]   PSIA    AVG BURNER OUTLET TEMP 1502. DEG F
AVG BURNER DELTA P       7.42    "HG     PRESSURE LOSS               6.07 %
OVERALL F/A RATIO       .01445  (F/F)    FUEL FLOW RATE            104.01 LB/HR
AIR LOAD FACTOR         1.[illegible]            PATTERN FACTOR             .10391
HOT HOT SPOT  # 36 = 1668.  DEG F        MAX BOT / AVG BOT          1.1105
FUEL INLET TEMPERATURE 142.  DEG F       FUEL INLET PRESSURE       187.8  PSIA
HEAT LOADING PARAMETER  .37551E+07 BTU/HOUR/ATM/CUBIC FOOT

                  **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1[illegible].  8 1434. 15 1471. 19 1458. 24 1537. 27 1597. 36 1668.
ANNULUS 2   4 1[illegible]5.  7 1537. 16 1419. 21 1385. 25 1526. 34 1618. 37 1555.
ANNULUS 3   5 1537. 14 1276. 17 1274. 22 1368. 26 1484. 35 1438. 39 1423.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          [illegible].49   PSIA   TOTAL PRESSURE          60.04   PSIA
STATIC PRESSURE         5[illegible].79  PSIA   STATIC PRESSURE         59.76   PSIA
VELOCITY DELTA P          .57    "HG    VELOCITY DELTA P          .68    "HG
AIR TEMPERATURE         [illegible].  DEG F   AIR TEMPERATURE          680.  DEG F
AIR VELOCITY            124.30 FT/SEC   AIR VELOCITY            133.44 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           .900    "HG

AIR FLOW DATA: P-REF= 104.3 PSIA    DELTA P=27.44 "HG    T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       [illegible].     HZ     VOLUMETRIC FLOW RATE  16.00 GAL/HR
FUEL PRESSURE AT F/M   [illegible]5.3    PSIA    FUEL TEMP AT F/M         142.  DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    58.40 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE            58.33 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.42  "HG (XDUCER # 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2   2.[illegible]77 %    O2  15.8[illegible] %    CO    67.7 PPM     CHX       .5 PPM
NO    30.6 PPM   NO2    9.7 PPM   NOX   40.3 PPM (NO(NDIR) + NO2(NDUV))
NO      .0 PPM   NO2     .6 PPM   NOX     .6 PPM ( CHEMILUMINESCENCE  )
EMISSIONS INDEX, LB/1000 LB FUEL: CO=   5.90                  CHX=    .06
                 CHEMILUMINESCENCE NOX=   .09,   NDIR + NDUV NOX=   5.16

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .013878
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  98.8387 %
   CHECK ON F/A RATIO- F/A = .013787 W/O O2, CALCULATED O2 = 16.986 %

SMOKE INDEX: 3.94
SALTZMAN NOX = 56.2                 PPM
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Figure 437. Final Modified Conventional Liner Modification "B" Parametric Test at Nominal Conditions.

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T63 COMBUSTOR EXPERIMENTS - RIG E/U 78, TEST SERIES 88, READING #     979
T63 MODIFIED CONVENTIONAL LINER, MOD "B" NOX PARAMETRIC STUDIES.
TEST DATE:  6-16-72                      READING WAS TAKEN AT 13551 2 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  50 % CLOSED        0 % POWER SETTING

                  ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW        1.959 LB/SEC    AVG BURNER INLET TEMP  1002. DEG F
AVG BURNER INLET PRES  61.5   PSIA     AVG BURNER OUTLET TEMP 1469. DEG F
AVG BURNER DELTA P     10.30   "HG     PRESSURE LOSS            9.36 %
OVERALL F/A RATIO     .00350  (F/F)    FUEL FLOW RATE          61.70 LB/HR
AIR LOAD FACTOR        1.2630          PATTERN FACTOR          .17669
HOT HOT SPOT: # 36 = 1587.  DEG F      MAX BOT / AVG BOT       1.0586
FUEL INLET TEMPERATURE 198.  DEG F     FUEL INLET PRESSURE      76.7   PSIA
HEAT LOADING PARAMETER  .22133E+07 BTU/HOUR/ATM/CUBIC FOOT

              **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1554.  6 1574. 15 1479. 19 1485. 24 1528. 27 1503. 36 1587.
ANNULUS 2   4 1581.  7 1540. 16 1454. 21 1440. 25 1521. 34 1551. 37 1523.
ANNULUS 3   5 1513. 14 1364. 17 1364. 22 1428. 26 1480. 35 1479. 39 1431.

LEFT SIDE           *** AIR INLET TUBE CONDITIONS ***           RIGHT SIDE
TOTAL PRESSURE          60.49    PSIA    TOTAL PRESSURE         60.54   PSIA
STATIC PRESSURE         60.09    PSIA    STATIC PRESSURE        60.17   PSIA
VELOCITY DELTA P         .82      "HG    VELOCITY DELTA P        .75     "HG
AIR TEMPERATURE         1002.  DEG F     AIR TEMPERATURE        1042.  DEG F
AIR VELOCITY           183.38 FT/SEC     AIR VELOCITY          175.65 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))         -.090    "HG

AIR FLOW DATA: P-REF= 104.4 PSIA   DELTA P=27.50 "HG   T-REF= 112. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY      231.      HZ    VOLUMETRIC FLOW RATE  10.86 GAL/HR
FUEL PRESSURE AT F/M   374.9    PSIA    FUEL TEMP AT F/M      100.  DEG F

              ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    55.40 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             58.00 PSIA (XDUCER = 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               10.25  "HG (XDUCER = 13)

                  * CHEMICAL ANALYSIS RESULTS *
                  GAS SAMPLES TAKEN IN PLANE #1
CO2   1.769 %     O2   18.500 %     CO     48.7 PPM     CHX      .2 PPM
NO    45.0 PPM   NO2     6.4 PPM   NOX    51.5 PPM (NO(NDIR) + NO2(NDUV))
NO      .0 PPM   NO2      .0 PPM   NOX      .0 PPM ( CHEMILUMINESCENCE  )
EMISSIONS INDEX, LB/1000 LB FUEL: CO=   4.82                  CHX=    .04
              CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=   8.00

    CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .008910
  CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8509 %
    CHECK ON F/A RATIO- F/A = .008407 W/O C2, CALCULATED O2 = 18.533 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 57.8              PPM
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Figure 438. Final Modified Conventional Liner Modification "B" Parametric Test at BIT = 1000°F.

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T63 COMBUSTION EXPERIMENTS - RIG P/N 76, TEST SERIES 80, READING #     980
T63 MODIFIED CONVENTIONAL LINER, MOD "B"  FOR PARAMETRIC STUDIES.
TEST DATE:  8-16-72                          READING WAS TAKEN AT 1436140 HOURS

CYCLE POINT  7     VARIABLE GEOMETRY  50 % CLOSED          0 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.815 LB/SEC      AVG BURNER INLET TEMP    598. DEG F
AVG BURNER INLET PRES  59.8   PSIA         AVG BURNER OUTLET TEMP 1490. DEG F
AVG BURNER DELTA P      15.89    "HG       PRESSURE LOSS            13.06 %
OVERALL F/A RATIO       .01442  (F/P)      FUEL FLOW RATE          146.14 LB/HR
AIR LOAD FACTOR         1.5317             PATTERN FACTOR           .17443
HOT HOT SPOT: # 36 = 1655.  DEG F          MAX BOT / AVG BOT        1.1840
FUEL INLET TEMPERATURE 108.  DEG F         FUEL INLET PRESSURE      196.0   PSIA
HEAT LOADING PARAMETER   .5349E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1612.  6 1541. 15 1455. 19 1443. 24 1521. 27 1504. 36 1655.
ANNULUS 2   4 1[illegible].  7 1644. 16 1413. 21 1367. 25 1575. 34 1500. 37 1536.
ANNULUS 3   5 15[illegible]. 14 1245. 17 1281. 22 1368. 26 1493. 35 1472. 39 1402.

LEFT SIDE             *** AIR INLET TUBE CONDITIONS ***               RIGHT SIDE
TOTAL PRESSURE           59.78    PSIA     TOTAL PRESSURE          59.77    PSIA
STATIC PRESSURE          59.18    PSIA     STATIC PRESSURE         59.10    PSIA
VELOCITY DELTA P          1.34     "HG     VELOCITY DELTA P         1.10     "HG
AIR TEMPERATURE          598.   DEG F      AIR TEMPERATURE         598.   DEG F
AIR VELOCITY            201.96 FT/SEC      AIR VELOCITY           189.17 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))             -.012     "HG

AIR FLOW DATA: P-METER 172.7 PSIA   DELTA P=81.48 "HG    T-REF= 112. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        544.      HZ     VOLUMETRIC FLOW RATE  23.01 GAL/HR
FUEL PRESSURE AT F/M    343.6     PSIA     FUEL TEMP AT F/M        108.   DEG F

                  ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    51.96 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE                55.03 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                   15.80   "HG (XDUCER # 13)

                       * CHEMICAL ANALYSIS RESULTS *
                        GAS SAMPLES TAKEN IN PLANE #1
CO2    2.751 %      O2   16.900 %      CO    190.7 PPM      CHX       .0 PPM
 NO    26.0 PPM   NO2     11.5 PPM   NOX      37.8 PPM (NO(NDIR) + NO2(NDUV))
 NO      .0 PPM   NO2       .0 PPM   NOX        .0 PPM ( CHEMILUMINESCENCE  )
EMISSIONS INDEX, LB/1000 LB FUEL: CO=  18.88                       CHX=     .00
                  CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=    4.18

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:          .013388
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.7211 %
   CHECK ON F/A RATIO- F/A = .013194 W/O O2, CALCULATED O2 = 17.186 %

SMOKE INDEX: 0.25
SALTZMAN NOX : 40.0                   PPM
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Figure 439. Final Modified Conventional Liner Modification "B" Parametric Test at Airflow = 3 lb/sec.

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T63 COMBUSTION EXPERIMENTS - RIG R/D 70, TEST SERIES 88, READING #    981
T63 MODIFIED CONVENTIONAL LINER, MOD "B" FOR PARAMETRIC STUDIES.
TEST DATE: 8-18-72                          READING WAS TAKEN AT 1458125 HOURS

CYCLE POINT  7     VARIABLE GEOMETRY  50 % CLOSED          0 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2,080 LB/SEC     AVG BURNER INLET TEMP    681. DEG F
AVG BURNER INLET PRES  33.7   PSIA        AVG BURNER OUTLET TEMP 1585. DEG F
AVG BURNER DELTA P      10.01   "HG       PRESSURE LOSS             23.35 %
OVERALL F/A RATIO      .01533  (F/A)      FUEL FLOW RATE           118.34 LB/HR
AIR LOAD FACTOR         1.9557            PATTERN FACTOR           .17109
MAX HOT SPOT: #  2 = 1850.  DEG F        MAX BOT / AVG BOT        1.1031
FUEL INLET TEMPERATURE 130.  DEG F       FUEL INLET PRESSURE      140.6  PSIA
HEAT RELEASE PARAMETER  .71312E+07 BTU/HOUR/ATM/CUBIC FOOT

                 **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1502.  8 1840. 15 1459. 18 1442. 24 1539. 27 1631. 36 1659.
ANNULUS 2   4 1842.  7 1650. 16 1416. 21 1355. 25 1541. 34 1615. 37 1530.
ANNULUS 3   5 1501. 14 1271. 17 1263. 22 1371. 26 1513. 35 1473. 38 1403.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***            RIGHT SIDE
TOTAL PRESSURE           33.67    PSIA    TOTAL PRESSURE           33.76   PSIA
STATIC PRESSURE          33.18    PSIA    STATIC PRESSURE          33.17   PSIA
VELOCITY DELTA P          .99     "HG     VELOCITY DELTA P         1.00    "HG
AIR TEMPERATURE          681.   DEG F     AIR TEMPERATURE          681.   DEG F
AIR VELOCITY            231.13 FT/SEC     AIR VELOCITY           241.14 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))            -.453    "HG

AIR FLOW DATA: PUPSTR= 140.5 PSIA   DELTA P=27.52 "HG    T-REF= 112. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        411.      HZ    VOLUMETRIC FLOW RATE  17.89 GAL/HR
FUEL PRESSURE AT F/M     484.5    PSIA    FUEL TEMP AT F/M         109.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     25.82 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE             30.85 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                15.99  "HG (XDUCER # 13)

                      * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    2.993 %     O2   16.402 %      CO    494.3 PPM     CHX       .3 PPM
NO     11.3 PPM   NO2      9.7 PPM   NOX     21.0 PPM (NO(NDIR) + NO2(NDUV))
NO       .0 PPM   NO2       .0 PPM   NOX       .0 PPM ( CHEMILUMINESCENCE  )
EMISSIONS INDEX, LB/1000 LB FUEL: CO=  27.18                     CHX=     .03
                    CHEMILUMINESCENCE NOX=    .00,   NDIR + NDUV NOX=    2.21

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .014981
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.3330 %
   CHECK ON F/A RATIO- F/A = .014272 W/O O2, CALCULATED O2 = 16.882 %

SMOKE INDEX: 0.00
SALTZMAN NOX = 28.3               PPM
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Figure 440. Final Modified Conventional Liner Modification "B" Parametric Test at BIP = 30 psia.

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T63 COMBUSTION EXPERIMENTS - RIG H/L 7P, TEST SERIES 8B, READING #    982
T63 MODIFIED CONVENTIONAL LINER, MOD "B" RUN PARAMETRIC STUDIES.
TEST DATE:  8-18-72                      READING WAS TAKEN AT 1525157 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  50 % CLOSED        0 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.024 LB/SEC    AVG BURNER INLET TEMP   600. DEG F
AVG BURNER INLET PRES   58.2    PSIA     AVG BURNER OUTLET TEMP 1098. DEG F
AVG BURNER DELTA P       7.49    "HG     PRESSURE LOSS             6.11 %
OVERALL F/A RATIO       .00766  (F/F)    FUEL FLOW RATE           55.79 LB/HR
AIR LOAD FACTOR         1.0946           PATTERN FACTOR          .17483
BOT HOT SPOT:  # 36 # 1186.  DEG F       MAX BOT / AVG BOT       1.0794
FUEL INLET TEMPERATURE 111.   DEG F      FUEL INLET PRESSURE       73.6  PSIA
HEAT LOADING PARAMETER  .20093E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
             ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP
ANNULUS 1   2 1155.   8 1171.  15 1071.  19 1082.  24 1119.  27 1149.  36 1186.
ANNULUS 2   4 1172.   7 1170.  18 1048.  21 1048.  25 1111.  34 1146.  37 1129.
ANNULUS 3   5 1110.  14  965.  17  975.  22 1026.  26 1073.  35 1099.  39 1053.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***              RIGHT SIDE
TOTAL PRESSURE            60.18   PSIA    TOTAL PRESSURE          60.20    PSIA
STATIC PRESSURE           59.86   PSIA    STATIC PRESSURE         59.93    PSIA
VELOCITY DELTA P            .65    "HG    VELOCITY DELTA P          .56     "HG
AIR TEMPERATURE            600.  DEG F    AIR TEMPERATURE          599.  DEG F
AIR VELOCITY             124.87 FT/SEC    AIR VELOCITY           126.88 FT/SEC
DIFFERENTIAL PRESSURE  ((LEFT P-TOTAL)-(RIGHT P-TOTAL))           -.035     "HG

AIR FLOW DATA: PREF= 124.8 PSIA    DELTA P=28.19 "HG    T-REF= 111. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       209.       HZ    VOLUMETRIC FLOW RATE    9.10 GAL/HR
FUEL PRESSURE AT F/M   641.8      PSIA    FUEL TEMP AT F/M        109.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE     58.51 PSIA
COMBUSTION OUTER CASE STATIC PRESSURE              58.44 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                  7.47  "HG (XDUCER # 13)

                   * CHEMICAL ANALYSIS RESULTS *
                   GAS SAMPLES TAKEN IN PLANE #1
CO2    1.530 %     O2  18.500 %     CO    152.8 PPM     CHX       .3 PPM
NO      12.7 PPM   NO2      0.1 PPM  NOX    22.7 PPM (NO(NDIR) + NO2(NDUV))
NO        .0 PPM   NO2       .0 PPM  NOX      .0 PPM ( CHEMILUMINESCENCE  )
EMISSIONS INDEX, LB/1000 LB FUEL: CO=  19.19                     CHX=     .08
               CHEMILUMINESCENCE NOX=     .00,    NDIR + NDUV NOX=    4.33

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:         .007541
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.5260 %
   CHECK ON F/A RATIO= F/A = .007414 W/O O2, CALCULATED O2 = 18.000 %

SMOKE INDEX: 0.22
SALTZMAN NOX = 26.0             PPM
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Figure 441. Final Modified Conventional Liner Modification "B" Parametric Test at BOT = 1100°F.

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T63 COMBUSTION EXPERIMENTS - RIG E/U 70, TEST SERIES 88, READING #    983
T63 MODIFIED CONVENTIONAL LINER, MOD "B"  FOR PARAMETRIC STUDIES.
TEST DATE:  8-16-72                        READING WAS TAKEN AT 1545122 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  50 % CLOSED        0 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          2.032 LB/SEC    AVG BURNER INLET TEMP     600. DEG F
AVG BURNER INLET PRES   59.7   PSIA      AVG BURNER OUTLET TEMP   1873. DEG F
AVG BURNER DELTA P       7.74   "HG      PRESSURE LOSS              6.37 %
OVERALL F/A RATIO      .02099  (F/F)     FUEL FLOW RATE           153.53 LB/HR
AIR LOAD FACTOR        1.1065            PATTERN FACTOR            .28234
BOT HOT SPOT:  # 36 = 2130.  DEG F       MAX BOT / AVG BOT         1.1375
FUEL INLET TEMPERATURE 111.  DEG F       FUEL INLET PRESSURE       216.6   PSIA
HEAT LOADING PARAMETER  .55764E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 2011.  6 2056. 15 1813. 19 1792. 24 1685. 27 1973. 36 2130.
ANNULUS 2   4 2055.  7 2070. 16 1750. 21 1698. 25 1880. 34 2020. 37 2081.
ANNULUS 3   5 1914. 14 1546. 17 1482. 22 1658. 26 1831. 35 1789. 39 1895.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE          59.69   PSIA    TOTAL PRESSURE           59.67   PSIA
STATIC PRESSURE         59.37   PSIA    STATIC PRESSURE          59.38   PSIA
VELOCITY DELTA P          .66    "HG    VELOCITY DELTA P           .59    "HG
AIR TEMPERATURE          600.  DEG F    AIR TEMPERATURE           600.  DEG F
AIR VELOCITY           141.10 FT/SEC    AIR VELOCITY            133.65 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]          .033    "HG

AIR FLOW DATA: P-REF= 104.5 PSIA   DELTA P=28.43 "HG    T-REF= 111. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       573.      HZ     VOLUMETRIC FLOW RATE  25.06 GAL/HR
FUEL PRESSURE AT F/M   403.6     PSIA     FUEL TEMP AT F/M       111.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    55.88 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             57.85 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                7.75  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                      GAS SAMPLES TAKEN IN PLANE #1
CO2    4.164 %     O2   14.700 %     CO     61.8 PPM     CHX      .0 PPM
NO      68.1 PPM   NO2    11.5 PPM   NOX    79.6 PPM (NO(NDIR) + NO2(NDUV))
NO        .0 PPM   NO2      .0 PPM   NOX      .0 PPM [ CHEMILUMINESCENCE  ]
EMISSIONS INDEX, LB/1000 LB FUEL: CO=   3.85                  CHX=     .00
                  CHEMILUMINESCENCE NOX=   .00,    NDIR + NDUV NOX=   6.15

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:        .020233
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8835 %
   CHECK ON F/A RATIO- F/A = .019766 W/O O2, CALCULATED O2 = 15.194 %

SMOKE INDEX: 4.05
SALTZMAN NOX = 88.5              PPM
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Figure 442. Final Modified Conventional Liner Modification "B" Parametric Test at BOT = 1900°F.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 88, READING #      984
T63 MODIFIED CONVENTIONAL LINER, MOD "B"  RUN PARAMETRIC STUDIES,
TEST DATE:  8-16-72                     READING WAS TAKEN AT 1604119 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  50 % CLOSED          0 % POWER SETTING

                    ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW          1.010 LB/SEC    AVG BURNER INLET TEMP    600. DEG F
AVG BURNER INLET PRES   60.0    PSIA     AVG BURNER OUTLET TEMP 1508. DEG F
AVG BURNER DELTA P       1.75    "HG     PRESSURE LOSS             1.43 %
OVERALL F/A RATIO       .01456  (F/P)    FUEL FLOW RATE           53.33 LB/HR
AIR LOAD FACTOR         .5523            PATTERN FACTOR          .17776
BOT HOT SPOT:  # 36 = 1660.  DEG F      MAX BOT / AVG BOT        1.1067
FUEL INLET TEMPERATURE 112.   DEG F      FUEL INLET PRESSURE       74.8   PSIA
HEAT LOADING PARAMETER   .19277E+07 BTU/HOUR/ATM/CUBIC FOOT

                   **** BURNER OUTLET TEMPERATURE SURVEY ****
            ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP   ID TEMP
ANNULUS 1   2 1556.   6 1597.  15 1527.  19 1519.  24 1558.  27 1614.  36 1660.
ANNULUS 2   4 1531.   7 1590.  16 1471.  21 1422.  25 1540.  34 1567.  37 1547.
ANNULUS 3   5 1466.  14 1295.  17 1293.  22 1375.  26 1478.  35 1438.  39 1386.

LEFT SIDE            *** AIR INLET TUBE CONDITIONS ***             RIGHT SIDE
TOTAL PRESSURE           59.97    PSIA    TOTAL PRESSURE          59.98   PSIA
STATIC PRESSURE          59.87    PSIA    STATIC PRESSURE         59.93   PSIA
VELOCITY DELTA P           .21    "HG     VELOCITY DELTA P          .19    "HG
AIR TEMPERATURE           600.   DEG F    AIR TEMPERATURE         600.   DEG F
AIR VELOCITY            53.06 FT/SEC      AIR VELOCITY            54.36 FT/SEC
DIFFERENTIAL PRESSURE: ((LEFT P-TOTAL)-(RIGHT P-TOTAL))          -.015    "HG

AIR FLOW DATA: P-REF= 105.7 PSIA    DELTA P= 6.56 "HG    T-REF= 110. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY        276.      HZ     VOLUMETRIC FLOW RATE    8.71 GAL/HR
FUEL PRESSURE AT F/M    490.0    PSIA      FUEL TEMP AT F/M         111.  DEG F

                 ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE    59.11 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE             59.78 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE                1.74  "HG (XDUCER # 13)

                     * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2    3.183 %      O2  16.140 %       CO      65.4 PPM     CHX     1.0 PPM
 NO     54.3 PPM   NO2    14.7 PPM   NOX      69.0 PPM [NO(NDIR) + NO2(NDUV)]
 NO       .0 PPM   NO2      .0 PPM   NOX        .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=   4.60                    CHX=     .10
                 CHEMILUMINESCENCE NOX=    .00,    NDIR + NDUV NOX=     7.63

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:            .015522
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.8616 %
   CHECK ON F/A RATIO- F/A = .015188 W/O O2. CALCULATED O2 = 16.560 %

SMOKE INDEX: 20.12
SALTZMAN NOX = 69.1                  PPM
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Figure 443. Final Modified Conventional Liner Modification "B" Parametric Test at Airflow = 1 lb/sec.

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T63 COMBUSTOR EXPERIMENTS - RIG B/U 70, TEST SERIES 88, READING #     985
T63 MODIFIED CONVENTIONAL LINER, MOD "B"  RUN PARAMETRIC STUDIES,
TEST DATE:  8-18-72                    READING WAS TAKEN AT 1628:17 HOURS

CYCLE POINT  7    VARIABLE GEOMETRY  50 % CLOSED        0 % POWER SETTING

                   ***** EXPERIMENTAL CONDITIONS *****
BURNER AIR FLOW         2.032 LB/SEC    AVG BURNER INLET TEMP   599. DEG F
AVG BURNER INLET PRES  90.6    PSIA     AVG BURNER OUTLET TEMP 1497. DEG F
AVG BURNER DELTA P      4.75    "HG     PRESSURE LOSS             2.58 %
OVERALL F/A RATIO      .01398  (F/M)    FUEL FLOW RATE          102.23 LB/HR
AIR LOAD FACTOR        .7300            PATTERN FACTOR          .16109
BOT HOT SPOT:  # 36 = 1641.  DEG F      MAX BOT / AVG BOT       1.0966
FUEL INLET TEMPERATURE 114.  DEG F      FUEL INLET PRESSURE     156.3  PSIA
HEAT LOADING PARAMETER  .24469E+07 BTU/HOUR/ATM/CUBIC FOOT

                **** BURNER OUTLET TEMPERATURE SURVEY ****
           ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP  ID TEMP
ANNULUS 1   2 1581.  6 1606. 15 1480. 19 1468. 24 1539. 27 1607. 36 1641.
ANNULUS 2   4 1626.  7 1607. 16 1426. 21 1404. 25 1542. 34 1573. 37 1566.
ANNULUS 3   5 1510. 14 1275. 17 1266. 22 1367. 26 1496. 35 1402. 39 1453.

LEFT SIDE              *** AIR INLET TUBE CONDITIONS ***        RIGHT SIDE
TOTAL PRESSURE           90.57   PSIA    TOTAL PRESSURE         90.58   PSIA
STATIC PRESSURE          90.30   PSIA    STATIC PRESSURE        90.39   PSIA
VELOCITY DELTA P           .55    "HG    VELOCITY DELTA P         .38    "HG
AIR TEMPERATURE           599.  DEG F    AIR TEMPERATURE         599.  DEG F
AIR VELOCITY           104.73 FT/SEC     AIR VELOCITY           86.87 FT/SEC
DIFFERENTIAL PRESSURE: [(LEFT P-TOTAL)-(RIGHT P-TOTAL)]         -.010    "HG

AIR FLOW DATA: P-REF= 104.3 PSIA   DELTA P=28.34 "HG   T-REF= 100. DEG F

FUEL SYSTEM DATA:
FUEL F/M FREQUENCY       382.      HZ    VOLUMETRIC FLOW RATE  16.71 GAL/HR
FUEL PRESSURE AT F/M   540.1    PSIA     FUEL TEMP AT F/M        113.  DEG F

               ** MISCELLANEOUS TRANSDUCER READINGS **
MANIFOLD AVERAGE BURNER OUTLET TOTAL PRESSURE   88.24 PSIA
COMBUSTOR OUTER CASE STATIC PRESSURE            89.48 PSIA (XDUCER # 11)
BURNER DIFFERENTIAL TOTAL PRESSURE               4.74  "HG (XDUCER # 13)

                    * CHEMICAL ANALYSIS RESULTS *
                     GAS SAMPLES TAKEN IN PLANE #1
CO2   2.801 %     O2  16.500 %      CO     33.3 PPM     CHX       .0 PPM
 NO     57.9 PPM  NO2      8.1 PPM  NOX    65.0 PPM [NO(NDIR) + NO2(NDUV)]
 NO      .0 PPM   NO2      .0 PPM   NOX      .0 PPM [ CHEMILUMINESCENCE  ]
 EMISSIONS INDEX, LB/1000 LB FUEL: CO=  2.34                  CHX=     .00
                CHEMILUMINESCENCE NOX=   .00,   NDIR + NDUV NOX=   7.60

   CALCULATED FUEL/AIR RATIO FROM CHEMICAL ANALYSIS:       .013759
CALCULATED COMBUSTION EFFICIENCY FROM CHEMICAL ANALYSIS:  99.9127 %
   CHECK ON F/A RATIO- F/A = .013373 W/O O2, CALCULATED O2 = 17.096 %

SMOKE INDEX: 36.69
SALTZMAN NOX = 71.3              PPM
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Figure 444. Final Modified Conventional Liner Modification "B" Parametric Test at BIP = 90 psia.

TABLE XCIII. PARAMETRIC TEST RESULTS FOR FINAL MODIFIED CONVENTIONAL MODIFICATION "B" COMBUSTOR LINER

Reading Number	Airflow (lb/sec)	BIT (°F)	BIP (psia)	BOT (°F)	F/A	ΔP (%)	Flow Factor	Exhaust Temp. Profile T_{max}/T_{avg}	Exhaust Temp. Profile Pattern Factor	Exhaust Emissions Constituent CO (ppm)	Exhaust Emissions Constituent C_xH_y (ppm)	Exhaust Emissions Constituent NO_x (ppm)	Exhaust Emissions Constituent Smoke Index	Chemical Analysis Comb. Eff. (%)	Chemical Analysis F/A
984	1.018	600	60.0	1500	.01456	1.43	.5523	1.1067	.1778	69.4	1.0	69.0	20.12	99.86	.01552
979	2.000	600	60.0	1502	.01445	6.07	1.0843	1.1105	.1839	87.7	.5	46.3	3.94	99.83	.01388
980	2.815	595	59.8	1498	.01442	13.05	1.5317	1.1048	.1744	156.7	.0	37.5	.25	99.72	.01336
977	2.009	200	59.7	1501	.01988	3.89	.8636	1.1556	.1796	376.0	3.0	33.8	12.00	99.54	.01951
978	2.000	600	60.0	1502	.01445	6.07	1.0843	1.1105	.1839	87.7	.5	46.3	3.94	99.83	.01388
979	1.999	1002	60.5	1499	.00859	8.36	1.2630	1.0586	.1767	40.7	.2	51.5	.00	99.85	.00851
981	2.000	601	33.7	1505	.01533	23.35	1.9337	1.1031	.1717	424.3	.3	21.0	.00	99.33	.01458
976	2.000	600	60.0	1502	.01445	6.07	1.0843	1.1105	.1839	87.7	.5	46.3	3.94	99.83	.01388
985	2.032	599	90.6	1497	.01398	2.58	.7300	1.0966	.1511	33.3	.0	66.0	36.69	99.91	.01376
982	2.024	600	60.2	1098	.00766	6.11	1.0946	1.0794	.1748	150.8	.3	20.7	.02	99.53	.00754
978	2.000	600	60.0	1502	.01445	6.07	1.0843	1.1105	.1839	87.7	.5	46.3	3.94	99.83	.01388
983	2.032	600	59.7	1873	.02099	6.37	1.1085	1.1375	.2023	81.8	.0	79.6	4.05	99.88	.02023

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